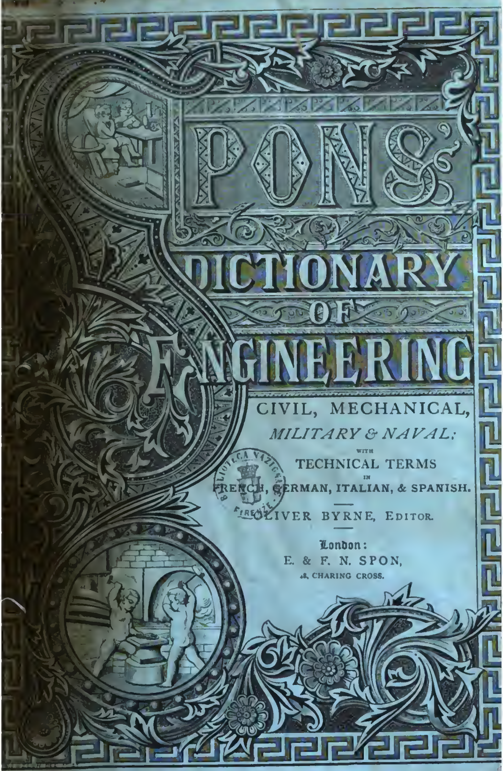

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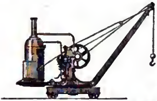

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to the metallurgist. In some cases the elements of composition have an influence on the results of the smelting operation. The same test which is used for sandstone is applied here. Good clay must shrink uniformly, not crack in drying, and form, after exposure to a strong heat, a compact solid mass, neither vitrified nor brittle. The mixing and tempering of clay has a decided influence on its refractive qualities, and good machinery and good furnaces are required to form good fire-brick. Some clays are plastic, that is, they may be moulded with great facility into any shape, which they will retain in drying and baking. This quality is caused by the presence of more or less soluble silex, and hydrated clay; anhydrous silex is not plastic. However valuable this quality of clay may be to the potter and manufacturer of porcelain, it is of little use to the metallurgist; all we want is, that clay should form a compact, hard substance which resists fire; the coarse forms in which it is applied do not require a particular degree of tenacity. In order to test clay, it is sufficient to mix it well by hand, and form it into slabs of half an inch in thickness, which are gently dried at first so as to prevent the formation of cracks, and then exposed to a strong heat. When clay is so fine or plastic as to crack in drying, it is necessary to mix it with sufficient fine, pure, silicious sand, to prevent that evil.

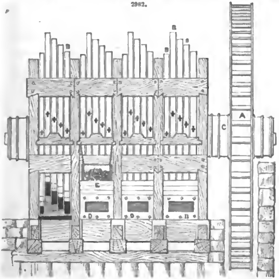
Green or fresh clay is not often applied at furnaces; it is, however, used in some smelting furnaces for repairs, and for hearths and boshes, when mixed with a large quantity of sand; also for forming bottoms in reverberatory furnaces, and others. Its chief use is for mortar.

Talcose Slate.—This substance often forms a very durable fire-proof stone, particularly when the slate has been exposed to a strong hardening heat in the native rock. This kind of slate forms soapstone when soft, but in that variety where it is cemented by heat it is extremely hard. This substance is extensively used as refractory stones in puddling furnaces, for which it is adapted by its resisting the influence of the oxides of metals exceedingly well.

Mica Slate.—This ranges with the talc slate, and in many instances it is very doubtful if the so-called talc slate is not actually mica slate, or merely a modification of it in form, characterized by the extreme minuteness of the leaves of mica. These slates resist fire well, if not too much mixed with metallic oxides, or with too much mica. The quantity of quartz determines the refractibility of the stone. This material is very convenient, because in most instances it is easily quarried and dressed to the desired forms. Chlorite slate, gneiss, porphyry, granite, and similar substances, resist fire in some instances very well; but their quality depends entirely on a peculiar composition. As a rule, these rocks are not very refractory, and are all liable to be broken by heat.

Artificial Stones; Fire-brick.—When natural stones cannot be obtained, or the purpose requires others, the substances of which artificial stones are composed, such as clay and silex, are pounded, ground together, and formed into bricks or slabs of any form that may be desired. Quartz, which is most in use, and in fact the only available substance besides clay, is pounded in stamping mills, such as represented in Fig. 2982. This operation is either performed dry, which causes much dust and premature destruction of machinery, or it is done by passing a current of water through the stamping box, and gathering the sand in a trough, in which it settles, and the water flows off. If the quartz is hard, such as river pebbles, or milky quartz, it may be exposed to a red heat in a roasting heap, after which it may be pounded quite easily.

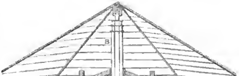
2982.



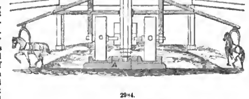
Of quartz, thus coarsely pounded to the size of a grain of wheat, or smaller, three parts are mixed with one part of plastic fire-clay; the whole well soaked with water, and diligently mixed, forms an excellent fire-proof sandstone, when merely air-dried. Of this mixture, bricks and slabs are easily formed, which may be used air-dried, in reverberatory, puddling, reheating, and all such furnaces, where no actual work or rubbing is done on the surface of the brick; for though they are fire-proof, they cannot resist abrasion when rubbed by solid matter. Bricks of this kind may be baked, but as they require rather a strong fire to make them compact, they are not generally; nor is much gained by a limited heat. These artificial sandstones, or fire-brick, are in many respects superior to the common fire-brick; they are cheap where the materials are close at hand, for the stamping is not expensive, and the moulding and drying causes hardly any expense. An air-dried brick is easily laid, and the joints are secured with remarkable facility, for the brick is suited to absorb the water from the mortar rapidly, which causes the latter to dry quickly; this affords an opportunity of using a large quantity of mortar; and as the mortar itself is but the solution of fragments of brick, the bricklayer's work is done very cheaply. In this case, as in all others, particular attention must be paid to the mixing of the clay and sand; too much labour cannot be expended on this part of the work. In mixing plastic clay with sand, it is the object to bring each particle of clay in contact with a particle of silex, and produce by that means a uniformity of mixture which is at the same time adhesive, and free from friable spots. This material, when well prepared, is eminently fitted for forming boshes, and even hearths, in furnaces. It may be used in the form of bricks, slabs, or what is the best, rammed down in a moist condition, so as to form one solid mass without joints.

When fire-bricks of a finer composition are required, such as are made of slaty clay, or of kaolin, or the silicious fire-clay of the eastern slope of the Alleghanies, it is necessary that the materials should be ground fine; this refers particularly to the slate clay. The clay of the coal regions, which is generally hard when newly dug, is exposed for some time to the atmosphere, under the influence of which it falls to small cubical pieces; and when exposed for a season to frost and the changes of temperature incident to winter, it is converted into a fine meal, which is easily ground. When quartz or sand is required for the increase of the refractory quality of the clay, it is mixed with it; or, when too coarse, it is ground first by itself, and then mixed in due proportions. The proportion of silex to clay cannot be determined by applying scientific principles; this must be found out by experiments, which are easily made by mixing various quantities, and exposing them to the same degree of heat. The quartz used for these purposes must be taken either from pure veins, or large quartz pebbles found in river bottoms. Sand obtained from pounded sandstone, or millstone grit, or river sand, is never sufficiently pure for fire-brick, or for retorts or crucibles. Clay thus mixed with quartz, or pure, is subjected to grinding in a mill similar to that represented in Fig. 2983. In most cases it is ground dry; some manufacturers grind it wet, because it works faster. The particles, when sufficiently fine, are swept away by the current of water, deposited in a box, and from thence removed to be tempered. The latter operation is frequently performed in the mill, Fig. 2983, and, in fact, is thought sufficient when the grinding is accomplished; but this is not the case. Some clay may require very little work; still, no harm is done by much tempering; good clay is often spoiled for want of the proper amount of work. An ill-made brick is porous and light; a good brick is compact and heavy; the first may be good enough for steam-boiler furnaces, but for smelting furnaces, where heat and fluxes, and the motion of fuel, cause abrasion, bricks should be as compact as flint. The latter quality is chiefly obtained by careful grinding and tempering. For this purpose a mill is used similar to those used for mixing loam for common bricks, which is shown in Fig. 2984. The main part of this machine is an iron or wooden cylinder, of from 3 to 4 ft. high, and 24 in. in diameter. When of wood, it forms an inverted cone, so as to admit of being firmly bound by iron hoops. In the centre of this clay-mill is a vertical shaft, provided with some radial knives. This shaft is frequently of wood, but is better when made of iron; the

2983.



2984.

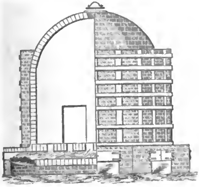


knives must be in all cases of iron. The latter are a little twisted, so as to cause the clay to move downward. The tempered clay is thrown in at the top, and the mill always kept full. At the lower end of the cylinder, close to the bottom, is a square hole, through which the clay is pressed, and issues continually. This square hole is provided with a gate, so as to regulate the quantity of clay which is permitted to pass. If the clay is not sufficiently mixed by passing it once through the mill, the process is repeated; in some cases this is required five or six times. In some instances the knives are provided with projecting points, so as to keep the clay in constant motion, as shown in the engraving; this may be advantageous, but it requires more power than plain knives, and a stronger machine than can be made of wood. This mill, of course, may be driven by horse-power, as shown, or by a water-wheel, or a steam-engine. When circumstances admit, it is advantageous to temper the clay when warm: this causes the air or gas in the pores of the clay to expand and escape, so that a close contact of the particles may be accomplished. It has been proposed to mix carbon, either in the form of graphite, or anthracite dust, or coke-dust, with the clay of which fire-bricks are to be made, but we are not aware that it has been put in practice to any extent. For crucibles, such a mixture is used; the black-lead pot is one of the kind, and the pots in which cast steel is melted are another kind; the latter are generally a composition of clay and coke-dust. For thin pots, and similar articles, we perceive no objection to coal, but in bricks and other heavy masses there are serious objections, which have been confirmed by experience. Coal, no matter in what form, causes always the formation of gas when in contact with oxides, such as clay and iron. If the substance is thin, such as a crucible, this gas may escape on the unglazed side; but if the mass is thick, it must escape at the hottest, or glazed, surface, and is the cause of a premature destruction of the fire-brick. Coal diminishes the shrinkage of clay, and thus far it is advantageous in the clay of crucibles, in preventing their fracture when in fire.

Fire-bricks are not generally manufactured from raw clay, at least not wholly of it; and there is no doubt but that a twice-burnt brick is superior to a brick made of fresh clay. The prepared and ground clay is subjected to one fire, either in the form of brick or in lumps, then ground and mixed with about one-third or one-fourth of fresh clay; this mixture is formed into bricks and baked. Some of our manufacturers do not follow this method, but there is no doubt, if their bricks are good now, they would be far better if baked twice. For this reason, brickbats, ground and mixed with a little fresh clay, will form a superior brick to the original brick made of raw clay.

Fire-bricks, in order to be baked, are generally subjected to a strong heat, in ovens built in a peculiar manner; this is not necessary if the bricks are not to be transported far, and if too much clay is not used in the mixture. In the latter case the brick is subject to much shrinkage, and when exposed to the heat in a furnace the joints between the various layers will separate and allow the heat to penetrate, which now acts on many sides and soon destroys it. All that kind of fire-proof material which must be transported, or in the composition of which a large amount of clay is necessary, must be baked; but those bricks which are manufactured and used on the spot, and which contain a large amount of silex, do not require baking previous to their use. In Fig. 2985 is represented a vertical section of an oven in which fire-bricks are baked. It is in appearance similar to a porcelain kiln, only not so large. The diameter is generally from 10 to 15 ft., and equally as high, according to the quantity of bricks to be made. One cubic foot of space will contain eight bricks of 10 by 5 in. The capacity of an oven is thus easily calculated. One charge will take a week's time—three days for baking and three for cooling. The oven is built wholly of fire-brick, secured by iron tires and vertical binders. The floor is also formed by fire-brick with draft-holes or flues, as shown in Fig. 2986, wherein four fire-places are indicated. This oven may be operated by one or two fire-places, but there is no harm done in having more of them. The fire-places may be without grate-bars in case wood is used as fuel; but when stone-coal is burned there must be grate-bars, which are withdrawn and the stock-holes shut with ashes when the baking is finished. At the top of the oven is a round aperture of about 20 in. in diameter, through which the hot gases escape: when the heat is at the highest degree this top is shut by an iron plate. At the floor there is an entrance of 3 ft. in height and 2 ft. in width, through which the oven is set, or

2985.



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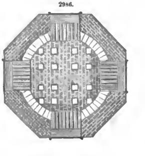
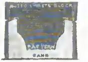


filled with bricks; this is temporarily shut with bricks, which are removed when the heat is finished and the oven cold. Through this door the bricks are also discharged. There are various forms of ovens, and also of mills, in use; the illustrations represent those most frequently found and to all appearances the best.

J. Jobson's Moulds for Casting Metals.—In the ordinary plan of moulding with odd-side boxes, the pattern from which the casting is to be made is imbedded partly in the sand of the top box, or in an odd-side board prepared for the purpose, and the bottom box is then placed upon it and rammed full of sand, imbedding the rest of the pattern; the boxes are then turned over, and the top box or odd side lifted off, leaving the pattern in the sand in the bottom box; parting sand is then applied, and another top box rammed upon it, the pattern still remaining between; the boxes are then separated, the odd side is again put on, the bottom box turned over, and the pattern left upon the odd side. After the impression of the pattern in the sand of the two boxes has been completed, by repairing any damage done in removing the pattern, the top box is again placed upon the bottom one in its original position, and the casting made.

In Jobson's process, after the pattern has been first partially imbedded in the sand of the bottom box as in ordinary moulding, Fig. 2987, and the parting surface been accurately formed, the top box is then placed on, and is filled with plaster of Paris, or other similar material, to which the pattern itself adheres. When the plaster is set, the boxes are turned over, the sand carefully taken out of the bottom box, and a similar process repeated with it, Fig. 2988, using clay wash to prevent the two plaster surfaces from adhering: this forms a corresponding plaster mould of the lower portion of the pattern. These two plaster moulds may be called the *waste blocks*, as they are not used in producing the moulds for casting, but are subsequently destroyed.

987.



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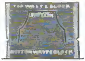

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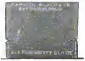

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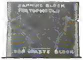

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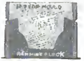

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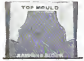

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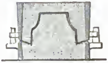


Finished Sand Mould.

Reversed moulds in plaster, Figs. 2989, 2990, are now made from these waste blocks, Figs. 2987, 2988 (the pattern being first removed), by placing upon the bottom box a second top box, an exact duplicate of the former top box, and filling it up with plaster (having used clay wash as before), and doing the same with the other box. Reversed moulds are thus obtained, from which the final sand moulds for casting are made, by using them as *ramming blocks*, upon which the sand forming the mould is rammed by placing a third duplicate top box, Fig. 2992, upon the ramming block, Fig. 2990, and a corresponding bottom box, Fig. 2991, upon the ramming block, Fig. 2989.

The requisite gits, runners, and risers are formed previously in the original sand mould, and are consequently represented in the ramming blocks, Figs. 2989, 2990, by corresponding projections or ribs upon the parting face of the one, and hollows in the other (which are then stopped up with plaster), and these are properly repeated in the final sand moulds, Figs. 2991, 2992; these last, therefore, when put together, as in Fig. 2993, form a complete mould for casting, just like an ordinary sand mould, but having some important advantages.

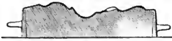
Any number of succeeding moulds can be made from the original ramming blocks by the simple process of ramming, without any handling of the pattern or turning over the boxes, both top and bottom moulds being rammed independently and at the same time if desired. The parting being once accurately formed in the original mould, all the succeeding ones are necessarily correct, without any further care being required; and by carefully trimming the original and slightly paring down the inner edges of the parting faces, if requisite, the faces of the final sand moulds have a corresponding fulness, and are readily adjusted, after the first trial, to fit so closely together that practically no fin is left on the castings. Also the labour of forming the gits and runners afresh for each casting mould is avoided, by having them completely imprinted upon each mould in the process of ramming: and by this means all the risk is avoided of imperfect castings arising from want of uniform care or judgment in the formation of the gits, &c., by the moulder in the ordinary process. This is the more important in the case of difficult castings, where several trials may be required before the best mode of running the metal is ascertained so as to ensure sound, good castings; and by this process the exact repetition of the same plan is ensured, without requiring any further attention from the moulder.

A small hollow is imprinted in the ramming block for the top box, into which the plug for forming the git is rested whilst the box is rammed, and by this means the git is ensured being formed in the right place, without any care on the part of the moulder.

The process of moulding by this plan is so simple and certain that ordinary labourers are quite sufficient to make the best castings, as they have nothing to do but ramming the sand upon the two blocks in each case, forming the back and front of the pattern, and putting them together without having to pay any attention to the parting gits or runners; and also it is much easier to lift the boxes when rammed off from the blocks, than to pick out the pattern from the face of the mould as in the ordinary process: the whole being in one solid mass in the new plan, it can be lifted more steadily, with less risk of injury to the sand mould.

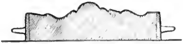
When the pattern is long and very thin and intricate (as in the case of an ornamental fender front) where the general surface is also curved or winding, as in Figs. 2994 to 2996, the difficulty of picking out the pattern from the mould is so great as to require the most skilful workman; and the length of time required for repairing the injuries of the mould, causes about eight sets of fender castings a day to be the general limit to the number that can be moulded by each man and boy. But however difficult the pattern may be to mould in the ordinary way (if it is arranged to draw properly from the mould), with the process of Jobson the labour is very little greater than with an easy pattern, and the saving of time is so great that as many as thirty a day are moulded on the average by one labourer and boy; being four times the number that the best moulders can produce by the ordinary plan.

2994.



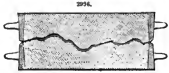
Ramming Block for Top Mould, with pattern secured on face of block.

2995.



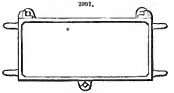
Ramming Block for Bottom Mould.

2996.



Finished Sand Mould.

2997.



Plan of Boxes.

When the pattern is slender and long it is liable to be broken in the frequent handling to which it is subjected in the ordinary process of moulding, and the expense and delay caused by breakage of patterns is of serious consequence in light ornamental work, where the patterns are often very expensive; but in the new plan this is entirely avoided, as the pattern is never handled at all except in the original process of moulding to form the ramming blocks.

When the face of the castings is required to be particularly well finished (as in the case of ornamental work) a brass or other metal pattern is made, and is dressed up and finished to the degree that may be desired in the castings, and any chasing or other additional ornament put upon it; then after forming the ramming block for the bottom box by a plaster-cast from the pattern in the manner before described (see Fig. 2995), the pattern itself is made to form the permanent face of the ramming block for the top box (as in Fig. 2994) by leaving it in the mould when the plaster is poured in, so that the plaster forms merely the parting face, and a solid back to the pattern. In this case, the iron pattern is secured to the cross-bars of the box by several small bolts screwed up to plates at the back of the box, so that when the plaster is poured in, filling up the whole vacant space of the box, and setting solid around these bolts and over these nuts, the iron pattern becomes so firmly secured in the box that no ramming or moving it is subjected to afterwards has any risk of loosening it.

In this plan the mould for the face of every casting is formed from the original metal pattern, and the pattern itself is firmly and permanently secured in the plaster bed, so that however thin and delicate it may be, there is no risk of injury to the pattern in moulding any number of castings. It is asserted in the P. I. M. E., 1854, from which this article is taken, that as many as 3000 have been cast without injury from a slender ornamental pattern.

In forming the ramming blocks, common plaster of Paris is generally employed, as the most convenient and economical material, and this is found to be sufficiently durable for general work; the blows of the rammer are deadened by the sand in the box, and do not fall directly upon the plaster block, so that there is no risk of injury with ordinary care in ramming. When a greater number of castings are required to be moulded from one pattern, or when the size or nature of the mould renders a harder face advisable, a metal face is employed for the ramming block of the bottom box, or for the parting surface of one or both blocks. This is formed simply by running into the mould, when prepared for the plaster, a small portion of metal, consisting of zinc hardened with about $\frac{1}{15}$ part of tin; sufficient metal being used to form a strong plate for the surface of the ramming block, and the rest of the space at the back filled with plaster as usual. In practice it is more convenient generally to reverse the mode of running this metal for the face of the mould, by first ramming the box, when prepared for the plaster, full of sand, then lifting it off, and paring off the surface of the sand wherever the metal is wanted to such depth (about $\frac{1}{8}$ of an inch) as may be desired for the metal, and when the box is replaced in its former position the metal is run in, filling up these spaces where the sand had been cut away. The sand in the upper box at the back of the metal face is then all removed, without moving the box (part at a time if requisite) and plaster poured in above to fill up the box and make a solid back as before.

The metal face is firmly secured to the plaster back by several small dovetail blocks cast upon the back of the metal, by cutting out corresponding holes in the sand mould before the metal is run in. Various modifications of this plan of construction are employed, according to circumstances, for economy or convenience, and sometimes the face of the ramming block is partially covered by separate pieces of metal: but in every case the entire face of the two ramming blocks forms a perfect counterpart of the intended casting (half being represented upon each), surrounded by parting faces which exactly fit one another, because the one has been moulded from the other.

Where the pattern is long, and a metal face is employed, a narrow division is made, subdividing the metal face into two or more lengths, to allow for the shrinking of the metal forming the face, the effect of which is then found to be imperceptible. The plaster ramming blocks are varnished when dried, to preserve them from damp; and in moulding from them, the faces of the blocks are dusted with rosin, to prevent adhesion of the sand.

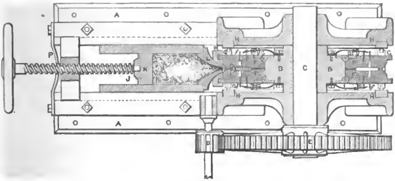
This process of producing blocks, though somewhat complicated in description, involves practically but little increase of work over the process of moulding required for the first casting produced by the ordinary method; but every subsequent casting, instead of requiring a repetition of the whole process of the first moulding, as in the ordinary method, is moulded by simply ramming the boxes upon their respective blocks. The ordinary odd-side boxes are used for this purpose, all that is requisite being that every top box fits steadily and securely upon every bottom box, so that they may be interchanged in the process of forming the ramming blocks, without disturbance of the relative position of the pattern. An improved form of the steady pins for connecting the top and bottom boxes has been adopted, as shown in Figs. 2993, 2997, which is easier to construct with accuracy. Instead of four or more round pins fixed on the bottom box, and fitting into corresponding holes in lugs cast upon the top box, vertical angular studs are cast on each bottom box, and fit against corresponding projections on the edge of the top box (as shown in the plan, Fig. 2997, and the section, Fig. 2993): the only fitting required in making the boxes is to file the touching angles of the pins so as to fit one standard top box, and the projections on the top boxes to be all fitted to one standard bottom box.

It has to be noticed that in the ordinary plan of moulding, and by the odd-side and plate methods, one side of a pattern is not available while the other is in use; by the process of Jobson each pattern is equal to two, as it will be evident that both blocks may be worked from at the same time.

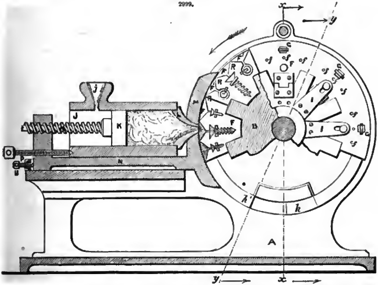
Casting Metals under Pressure, Smith and Locke's process for.—The apparatus which is here selected for illustration, but to which the invention is not necessarily restricted, consists of a rotary wheel or cylinder, Fig. 2999, on the periphery of which are arranged a series of moulds, each formed of a pair of hinged metallic plates, which while the casting is being performed are held firmly together between stationary housings, suitable rollers being interposed between the rotary mould-plate and the stationary housings to reduce the friction. Each of the mould-plates is provided with one or more springs, which, as the rotation brings the moulds successively opposite recesses in the housings, cause the mould-plates to separate with a sudden movement, causing a jar which effectually detaches and discharges the casting. This effect is assisted by pins which are driven inward as the mould-plate is separated, and in their retracted position form parts of the mould. The continued rotation of the wheel carries the mould-plates between converging planes, which gradually close the moulds and conduct their rollers between the parallel parts of the housings by which the plates are held to receive the molten metal which is injected into the moulds from a cylinder by a sliding piston or plunger. A detachable non-conducting lining is applied to the interior of the cylinder, K L, each time before it is filled, and serves the combined purposes of preventing the molten metal setting or adhering to the metallic cylinder, and effectually packing the joint between the moving piston and the cylinder. From this reservoir the metal is forced through a contracted aperture directly into the moulds, the gates of the latter being funnel-shaped, so as to cause no interruption to the passage of the metal. A continuous pressure is applied to the metal within the cylinder during the casting operation, and the partitions between the moulds being tapered to an edge cause no perceptible interruption to the flow as they pass the discharge orifice of the reservoir. The reservoir is mounted upon a sliding bed provided at its forward end with a segmental plate or standard which fits around the periphery of the cylinder, so as to tightly close the gates of the moulds, and serves also as a mouthpiece for the injecting cylinder. The sliding bed is held up to the cylinder by a screw and spring, the latter permitting it to yield, so as to avoid danger of breakage in the event of any hard matters getting between the mouthpiece-plate and the cylinder. The injecting and pressing apparatus may be used with equally good effect in connection with stationary moulds, the said moulds being arranged either separately or in any number together, and placed either horizontally or vertically; or in cases where it is desirable to cast a number of small articles at one time, any number of moulds, therefore, may be placed together within a single flask or casing, and a single injecting reservoir may be used for all. The molten metal may be made to enter the moulds horizontally, or may be forced upward from the lower part, or introduced at top, as convenience or various circumstances may dictate. For casting a large number of small articles simultaneously, the stationary moulds are preferably arranged in a vertical nest or series, and the metal injected at bottom, the separate moulds or parts of moulds being provided with suitable grooves to form, when united, gates or sprues for the admission of the fluid metal. A cluster or connected series of these moulds being placed together in their flask or casing are supported and firmly compressed by a plate, which is forced against the moulds by set screws tapped into the top, bottom, or side of the flask, in order that the moulds may resist the pressure of the metal when injected, and not part or open at the joints, and thereby cause the formation of fins or seams in casting. The entire flask may then be enclosed in a tight box from which the air can be exhausted by an air-pump of large capacity, small perforations being formed in the walls of the flask and in the body of the moulds to permit the escape of air and gas from all parts of the latter. Whenever the air and gas exhausting process is used, care must be taken that the joints of the outer chest are all tightly closed, and the junction between the said chest and the reservoir is luted with wet clay or other material to make all air-tight.

As a material for the moulds, steel and many other metals may be used to good advantage, especially for small moulds in a rotary apparatus, such as is represented in Figs. 2998 to 3000.

2998.



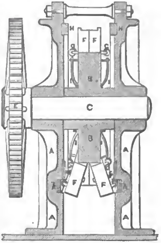
2999.



The great rapidity with which refractory metals chill and become set causes difficulty in the use of metal moulds, even though the said moulds may be heated prior to the introduction of the metal. This rapid setting would afford insufficient time for applying pressure to the metal, unless this is done instantaneously by apparatus such as we here describe, and even with the improved apparatus there is danger of the formation of a skin on the surface of the metal, which with elaborate or fine work may cause a mottled, streaked, seamed, or otherwise defective appearance. Again, if metal moulds are highly heated to prevent to a certain extent the sudden chilling, the fluid metal will unite with the moulds, especially the alloys of copper and tin; and even if metal moulds could be used with advantage, the expense of making them would forbid their use in cases where only a limited number of castings are wanted of one and the same pattern, and in some cases the utter impossibility of making them.

Where the diameter of the apparatus or the size of the flasks or mould-boxes or other circumstances will admit of it, it is better to form the moulds of a composition which will combine the following qualities, namely;—First, non-conductibility to heat; second, sufficient strength, density, and hardness to resist the pressure exerted on the fluid metal to prevent the latter entering the pores under such pressure, and to avoid danger of the fine lines and sharp corners being injured in necessary handling, or crushed or flattened by the pressure; third, the presence of numerous very small pores, which, while they will not permit the entrance of the molten metal under pressure, will allow the withdrawal of air and gas from the moulds.

3000.



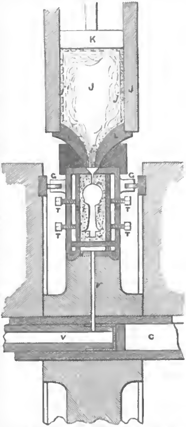
The production of composition moulds combining the above qualities constitutes one important part of this invention. They may be made as follows:—Take fine clay of such kinds as will resist a considerable degree of heat without glazing or melting on the surface. Said clay, after it has been well mixed and washed in the same manner as it is prepared for pottery, is made dry, so that it may be reduced to powder. When reduced to powder it is moistened with water about as much as sand used for ordinary moulding. The pattern, if it is to be used for a number of moulds, ought to be of metal. For one or two impressions, said pattern may be of hard plaster of Paris or hard wood. If of either of these two last-named materials, it must be first coated with shellac varnish; the pattern is then rubbed over with a little oil (preferably paraffine oil), applied with a brush, so that it may be released easily from the moist clay. After oiling, the pattern is coated over with a fine paste-like slip made of the same clay used for moulding. The pattern or a number of them are placed in an iron or brass flask or frame suitable for the size and thickness of the mould to be made, and provided with a bottom and plunger, or follower, and the flask is filled with the moist clay powder on the top of the pattern. Then the plunger or follower is placed in position, and the whole brought under a powerful press, and subjected to a slowly-applied but high pressure, say about 300 to 400 lbs. to the square inch, thereby packing and pressing the loose powder into a compact and solid block. After sufficient pressure is applied it is allowed to stand under the press for a few minutes, so that the surplus moisture or water in the slip may be absorbed by the more dry clay powder. The purpose of the slip is to unite the loose particles of the clay powder in direct contact with the pattern to a fine and homogeneous mass. The flask may then be removed from the press and the bottom taken off; this done, the pattern is easily taken out, and a mould will be found as perfect and smooth as if made of wax or gypsum. If a mould is to be made consisting of two or more parts, the first part made is coated on the surface coming in contact with the surface of the next part, to be made with a slight coat of collodion or thin shellac varnish, so as to make a partition between the clay surfaces, and they may be separated without difficulty. When the mould is completed it may be taken out of the flask or frame and handled and carried without danger of breaking. The moulds made are rendered dry by exposure to the influence of air or a gentle heat. When most of the moisture is evaporated, the moulds are placed into furnaces similar to those used for burning pottery, and the heat gradually raised until the moulds are red hot, which will burn them about as hard as a soft brick or clay-stone. When cooled off they are ready for casting. As it is necessary to keep these moulds in the same shape as when first made, and whereas articles made of clay are very liable to warp during the process of drying and burning, unless it is done with great care and waste of time, for the prevention of these evils it is found best to use to one part of clay powder made of fresh or new clay, another half of clay powder made of clay which has been previously burnt, or of old clay moulds which have been used for casting; the compound of these two different kinds of clay powder is very beneficial, as it prevents the warping of the moulds, even if they are of a considerably large size.

Fig. 2998 is a horizontal section of an apparatus; Fig. 2999 is a longitudinal section thereof, with part of the revolving wheel in elevation, part of it in section, and part entirely removed; Fig. 3000 is a vertical transverse section, the stationary parts being represented in the plane underneath by the line *x*, *x*, and the rotary mould-wheel in the plane of *y*, *y*, Fig. 2999; Fig. 3001 is a section of a part of the apparatus on a larger scale, illustrating a mode of withdrawing air and gas from the moulds prior to the injection of the metal.

A, A, represent various parts of the stationary frame; B is a wheel or cylinder attached to a shaft C, which is rotated by gearing D, E, or other means; F, F, are mould-plates hinged in pairs to the periphery of the wheel, and so constructed that each pair will join, when closed, a matrix to produce the article which it is desired to cast; *f*, *f*, represent pins employed to aid in the detachment and ejection of the casting from the moulds, as previously explained. The inner ends of the said pins are flush with the inner surface of the moulds when the latter are closed. The outer faces of the hinged mould-plates are furnished with friction rollers G which bear against the housings H, so as to hold the moulds in their closed condition to receive the metal; *h*, *h*, represent recesses in the housings permitting the moulds to be opened by the springs I, I, when the castings are to be discharged.

These recesses begin with abrupt shoulders h^1 to permit the moulds to open suddenly, and converge so as to conduct the friction rollers gradually up to the parallel parts of the housings H. The reservoir for molten metal consists of a cylinder J provided with a piston K, which may be moved by a screw K^1, or by a lever, in order to force the metal out through the detachable thimble or nozzle L. A funnel *j* may be formed upon or employed in connection with the reservoir J when it is to be used in a horizontal position. The nozzle L passes into a mouthpiece or guard-plate M, which serves to close the gates of the moulds, and is rigidly attached to or forms a part of the bed N, which supports the cylinder J. The bed N is adapted to slide, and is held up to its work by a screw O and spring P. Under the ordinary working of the machine the gates will be tightly closed, so as to prevent any escape of metal from the moulds until it is firmly set; but in the event of a fragment of metal or other matter passing between the periphery of the wheel and the guard-plate M, the latter will yield, and thus avoid injury to the apparatus; R, R, represent the tapering partitions between the gates F^1 of the moulds F. The said partitions converge to edges, so as to cause but momentary obstruction in passing the nozzle L, and to impart a funnel shape to the gates or sprues.

3001.



The reservoir may be used in vertical position, as shown in Fig. 3001, and the funnel *j*, Fig. 2999, dispensed with, the metal being introduced into the open upper end of the cylinder, and the piston K afterwards placed upon it. j^1 represents the detachable non-conducting lining with which the inner surface of the reservoir is coated prior to each time of charging it with molten metal. F^2, F^2, represent moulds of the clay composition hereinbefore described; S, S, plates, and T, T, set screws by which the said moulds are firmly pressed and held together so as to resist the pressure of the entering metal, and prevent any opening of the joints. The plates S, S, may serve as the mould-flask, or they may be placed within a separate flask, and the latter enclosed in an outer air-tight casing or box U from which air and gas are withdrawn prior to or during the casting operation through pipes *c*, V, by means of a powerful air-pump, or for some classes of work the air-tight box and exhausting process may be dispensed with. For some kinds of casting, especially in iron and steel, moulds of iron and steel may be used with good success, but it is very essential that such metal moulds be so arranged that the fluid iron or steel is injected as directly as possible, and without first passing through too long a space of *gates* or sprues before the mould is reached by the metal. The reason why this should be done is this,—if fluid refractory metals come in direct contact with other metal surfaces they chill and set more suddenly than those who are not acquainted with this property have an idea of, even if those surfaces should have been previously made red hot. The consequence of this action is that the casting will show streaks and an uneven surface; but if the moulds are filled directly from the injecting cylinder (avoiding the passing of the fluid metal over a long distance in the gates), and the strong pressure is brought to bear on the metal in the filled mould instantaneously before it has had time to form a hard skin or surface, a very good and sharp impression is thus obtained. Iron and steel moulds used in this manner ought to be oxidized or rusted on the surface to a certain extent. These rusted or oxidized surfaces are somewhat non-conductile, and serve also to prevent the adhering of the injected metal to the moulds.

When the suitable moulds are made they are put in a metal box or flask, and an iron follower employed to press and hold the moulds firmly together by means of the set screws, as illustrated in Fig. 3001, just as the style of the machine may be, so as to resist the pressure of the injected metal without parting at the joints. When this is done the cylinder or injecting vessel J is provided on the inside with a non-conducting lining.

The lining of the cylinder is performed as follows:—Take some fine fire-proof clay or *kaolin* free from sand grit, and thoroughly blend the same with about one-half the quantity of good plumbago; then mix with water so as to form a paste. The cylinder is heated to about 200° of Fahrenheit, and with a brush the aforesaid paste is applied on the inside of the cylinder to a uniform thickness of about $\frac{1}{4}$ of an inch, the heat of the iron cylinder drying the paste as applied. This done, the cylinder is further heated to evaporate all moisture from the lining, and is then ready for further operation. The surface of the piston K coming in contact with the fluid metal is coated in a similar manner. This lining of the cylinder serves several useful purposes; it serves to pack the space or joint between the cylinder and piston, and prevents the intrusion of the metal between the two, which intrusion would certainly and rapidly clog their parts and stop the operation, as the heat of the fluid metal will at once expand the cylinder more than the piston, and admit the metal between them at the joint. It should be explained that the plunger or piston K fits the cylinder, and is therefore larger than the internal diameter of the lining, and that at every operation the cylinder must be relined or recoated, as such lining is detached from the cylinder J, and pushed in advance of the piston K at every forward movement of the latter, the effect of which is to close the joint, and prevent the intrusion of the metal between the piston and side of the cylinder, as above stated. No matter how high the pressure is on the fluid metal, not a drop can leak out, the detached lining will pack the joint so much the more closely. The importance of this detachable lining can scarcely be over-estimated, since it forms by its non-conducting property the only practicable means for preventing the chilling or rapid setting, and also the adhering of the molten metal which would arrest the forward motion of the piston, and preclude any successful operation. Those acquainted with the nature of refractory metals know how rapidly they chill and set if they come in contact with another metal surface, even if said surface is made red hot, and it requires several minutes' time to fill the cylinder and perform the operation of injecting. This lining serves also to prevent the direct contact of the fluid metal with the surface of the cylinder, which would soon spoil the cylinder by the excessive heat of a mass of molten metal, even if the other aforesaid advantages were not of such great importance. The nozzle or thimble L (if made of metal) is lined in the same manner as the cylinder itself. The discharge orifice of the said nozzle is then stopped with a clay plug or tamp *l* capable of resisting a pressure of 6 or 8 lbs. to the square inch. The office of the plug or tamp *l* is to prevent the gradual passage of the metal into the moulds. All being in readiness, and the cylinder J charged with molten metal in quantity somewhat in excess of the capacity of the moulds to be filled and placed in proper position, a pressure of from 30 to 60 lbs. to the square inch, and sometimes more, may be applied to the metal by either a screw, lever, or other means; but experience will soon indicate to the practical operator the proper amount of pressure for various kinds of casting. When pressure is applied to the metal the plug will yield and pass along in the main gate, giving the metal free passage into the moulds. When the casting is performed and the metal is set, the cylinder is readily detached by breaking the metal in the gate at the junction of the thimble and the moulds. This ought to be done immediately after the casting is done, and before the metal in the gate has acquired its full strength by cooling off. The remaining head of metal in the cylinder is easily removed after cooling.

The operation of the rotary apparatus, represented in Figs. 2998 to 3000, may be described as follows;—Any number of the reservoirs J, K, L, may be prepared for use by coating their inner surfaces with a suitable non-conducting paste, and filling them with molten metal, the nozzle L being closed with a clay plug to prevent the escape of metal. The cylinder J being placed in the position shown in the drawings, the wheel B is set in motion, and then pressure is applied to the piston K so as to cause a continuous discharge of molten metal through the nozzle L. The small clay plug or stopper in the nozzle being driven out with the first discharge of metal may pass into one of the moulds and cause the production of a single imperfect casting, but after this a continuous jet of pure molten metal is kept up. The metal is thus injected and compressed into each mould as the rapid rotation of the wheel carries it in front of the nozzle. The guard-plate M prevents the escape of any of the metal until it has had time to become set, and as the bearing rollers G of each mould reach the shoulders h^1 of the recesses *h*, the springs I cause the mould-plates to separate instantaneously with a concussion which discharges the casting from the mould, or if the jar should be insufficient the driving of the pins *f* inwards through the mould-plates ensures the detachment of the casting.

The continued rotation of the wheel carries the rollers up the converging faces of the recesses *h* until they pass between the parallel faces of the housings H so as to effect the tight reclosure of the moulds in readiness for filling. For casting articles of larger weight than a quarter of a pound the motion of the wheel may preferably be intermittent instead of continuous. Where, from the character or size of the castings to be produced, the particular metal or alloy used therein, or other circumstances, it is found desirable to employ moulds of the clay composition in connection with the rotary apparatus, as illustrated in Fig. 3001, the said composition moulds may be arranged and secured in the several flasks or mould-chambers completely around the periphery of the wheel before the casting operation begins. The injecting reservoir J being then charged and set in position, and pressure applied to the piston K, a number of large compressed castings may be produced by a single revolution of the wheel, or in some cases it will be practicable to employ the composition moulds in continuous or repeated operation in the manner first described. While selecting to illustrate various parts of the invention the preferred styles or types thereof, it is not proposed to restrict it thereto so long as the same results are obtained by means substantially equivalent. For an example, the pressure of steam or condensed air may be applied to act on the piston, or steam or condensed air may even be used to exercise direct pressure on the fluid metal if the cylinder is in vertical position and the end of the cylinder closed, although practical experience has proved that the mechanical pressure is the most reliable and least complicated. It is also proposed in some cases to use a form of double flask, or a flask with two or more chambers connected by suitable gates, so that the molten metal may be placed in one and the moulds in the other or others, and the compression casting can be performed by forcing the metal out of the first chamber or the reservoir into the moulds, which are arranged and secured in the other chambers.

Another modification consists in the employment of a horizontal reservoir with its discharge aperture at or near the highest part, as the metal need not entirely fill the reservoir; when the piston is retracted no metal will be discharged until the piston moves, even if the plug or tamp be dispensed with, but to prevent cooling and oxidation it is preferable to use the plug in this case also. As a substitute for the clay plug or tamp a sliding rod or other form of valve may be employed, being adjusted to resist any pressure below a certain degree, and where the pressure exceeds that degree to yield and open the way between the reservoir and moulds.

It will be apparent that some of the principal parts of the invention, as for example the injecting process and apparatus, the material for the moulds, the manner of securing the moulds within the flask, and the exhausting process are not in any manner restricted in their use to the rotary apparatus which has been more particularly described in connection with Figs. 2998 to 3000, but may be used equally well with stationary or detached flasks. In practice it is rarely found necessary to employ the atmospheric exhaustion in connection with the compression of the metal, but its use is found advantageous in cases where it is especially necessary to produce castings of the most compact and solid character with entire freedom from blow-holes throughout. In these cases it is preferable to use the stationary rather than the rotary moulds, so that the exhaustion may be effected through a simple pipe connected to the air-tight chest within which the flask is enclosed. When the injecting reservoir is placed in a vertical position the use of a thimble L separate from the reservoir J, facilitates the removal of the reservoir by slipping it off vertically when the metal has become set. The superincumbent mass of metal remaining in the reservoir might render this difficult or impossible if the lower end of the reservoir itself were contracted or formed with an inwardly projecting flange or shoulder. If said thimble is made of iron or other metal it ought to be divided longitudinally into two parts, so that the same may be readily detached from the metal in the central gate, and the head left in the cylinder after casting. Continued practice has proved that the best manner of making said thimble is to form or make it by pressing moist clay into a suitable mould, and after forming to burn it hard in the manner that brick or pottery is burnt, and to use a new thimble at every operation of casting. Such mineral thimbles are strong enough, cheaply made, and easily detached by breaking them in pieces after casting. Practical founders know that if a mould could be used of a material more dense than sand or sand loam, a more perfect and sharp mould could be made, and there would not be so great liability of the sharp lines of the mould being washed by the inflowing metal; but they are also aware that if a mould is made so dense by ramming and stamping, or by the use of dense material, the gases generated and the air in the moulds will not be ejected by the mere pressure obtained by the weight of the metal itself; the consequence is that the metal is blown out of the mould and the casting is useless. The employment of the compression process applied to refractory metals, just described, enables the use of moulds of great density and of materials which will take a very fine and sharp impression of the patterns by great pressure applied to the material formed into moulds. By providing separate injecting vessels for the reception of the molten metal previous to its introduction into the mould, and having a high pressure to bear on the fluid metal in the very act of its rapid filling of the moulds, the elimination of the gases generated and the air in the moulds is compelled to take place through very fine pores and the small orifices made at the joints of the moulds; and as the pressure is kept on the metal until it is well set and solid, such a thing as blowing will never, or very seldom take place, but the metal is compelled to fill every cavity of the mould, producing a perfect, sharply defined, and smooth surface.

Moulds made of clay composition are especially well adapted to be used with this compressing casting apparatus. Moulds to be used for another more simple method of casting metal under pressure, but applicable only to the casting of larger pieces of one face, are made in the same manner, only it is preferable to use instead of ordinary clay the clay composition used for black-lead crucibles or for good fire-tiles. The only necessary difference in the manner of forming the mould is as follows;—The iron box or frame is first filled with clay powder, and the pattern is then placed with face down. The reason for doing so is that the clay mould is left in the iron box and the bottom of the box is not removable, therefore the pattern must be placed on the top of the powder that it may be taken out after the impression is produced. The iron box or flask used for the clay mould ought to be of the outside size and shape of the die or mould to be cast in metal, and the bottom ought to be provided with a hole or slot for the purpose presently to be seen. When the pattern is removed the clay mould is made dry; after drying and while still in the iron box it is placed in a muffle furnace, and the heat gradually raised until the mould and iron box are brought to a temperature nearly equal to that of the metal to be cast in it; while this is done the metal to be used is melted in another furnace. Then the clay mould is taken out of the furnace and filled with so much of the fluid metal as is necessary to make the articles, allowing a small surplus to be acted on by the follower. The surplus of metal is kept from overflowing by an iron collar or frame which extends above the clay moulds. When so far filled the follower is put on top of the fluid metal and then the whole is placed under a screw or lever press. During the time required to perform the filling of the mould and placing under the press, the fluid metal becomes mushy, or semi-fluid, and if pressure is applied the metal will take a perfectly sharp impression of the mould. When the whole is cooled off, the casting is removed out of the iron collar or box by driving something through the hole left for that purpose in the bottom of the box. The alloys of copper and tin are most favourable for this process of casting, but it may also be employed for other refractory metals and metal compositions with good success. The use of clay in this method of producing moulds for dies and other single-faced castings greatly reduces the care and skill required and the risk of loss involved in making such castings. In forming metal moulds with metal patterns, there is great danger of the injury or destruction of the pattern to be copied by the molten metal adhering to it. It is well known that moulds have been made of clay when in a plastic state for different purposes, and also that clay mixed with sand is employed for making moulds to be used for casting large bells and other heavy bronze and brass castings so as to give strength to the sand that it may resist the pressure of a great mass of metal. Now, those acquainted with the art of forming moulds and other things of plastic clay, know that it is very difficult and almost impossible to press plastic clay into deep cavities of a pattern, especially if the pattern is made of metal or other material of great density, because the air will always be more or less confined in the cavities and prevent the admission of the clay to produce a sharp and perfect impression. Another disadvantage, and that not the least, is that clay used in the plastic kneadable state will shrink very much, thereby reducing the size and changing the form of the article to be moulded; further, an article formed or moulded of plastic clay is very liable to warp and get out of shape by handling, and during the process of drying. But by using a moist clay powder and forming it into a compact mass by high pressure, those difficulties are entirely obviated; by using first a coating of slip applied over the pattern with a brush, the clay is brought into every cavity of the pattern at the commencement. Then the moist clay powder, being first in a loose state, attaining its strength and hardness gradually by the pressure slowly applied, permits of the easy escape of the air from the cavities of the pattern and throughout the whole mass, and produces a perfect and sharp impression. Further, by using moist clay powder, and making it a compact block by means of high pressure, the mould is, when formed comparatively to a mould made of plastic clay, in a greatly advanced state of dryness, may be handled and carried about without getting out of shape, and as it contains not one-fourth part as much water as plastic clay it is almost entirely relieved from shrinkage and adapted to retain the shape and size first given in making. Further, by mixing with fresh new clay powder one-half of powder made of burnt clay the mould is relieved from liability to warp and crack during the process of drying and burning. The application of slip made of clay as a facing closes the pores and unites the clay powder into a fine and plastic mass where it comes in direct contact with the pattern. The slip is rendered quickly plastic by absorption of the surplus of water it contains by the comparatively dry clay powder in the rear. Now, as the application of slowly applied pressure is believed to be new in this connection, it is proper to explain its importance. If an attempt is made to form the loose moist clay powder into a compact and solid mass, as a good mould must be by means of stamping and ramming as it is done in the ordinary way of moulding, it would naturally take a great deal of labour, but after removing the pattern the mould would be of insufficient and unequal compactness and imperfect impression; and further, when the mould was removed from the flask it would not properly hold together in burning, but fall to pieces as if the mould had been made of a number of layers of clay. If high pressure should be applied by means of machinery in a sudden manner, or with a momentum, the same results would occur. But, if pressure is applied slowly and gradually, the loose particles of the clay powder are gradually and firmly united into a solid compact mass of uniform density entering perfectly and sharply into every cavity of the pattern. The labour required to form a mould in the manner described is but little more than in forming a mould in the ordinary way of moulding.

Brass moulding is carried on by means of earthen or sand moulds. The formation of sand moulds is by no means so simple an affair as it would at first sight appear to be, as it requires long practical experience to overcome the disadvantages attendant upon the material used. The moulds must be sufficiently strong to withstand the action of the fluid metal perfectly, and, at the same time, must be so far pervious to the air as to permit of the egress of the gases formed by the action of the metal on the sand. If the material were perfectly air-tight, then damage would ensue from the pressure arising from the rapidity of the generation of the gases, which would spoil the effect of the casting, and probably do serious injury to the operator. If the gases are locked up within the mould, the general result is what moulders term a *blown* casting; that is, its surface becomes filled with bubbles of air, rendering its texture porous and weak, besides injuring its appearance.

Plaster of Paris is often used for a number of the more fusible metals. This material, however, will not answer for the more refractory ones, as the heat causes it to crumble away and lose its shape. Sand, mixed with clay or loam, possesses advantages not to be found in gypsum, and is consequently used in place of it, for brass and other alloys. In the formation of brass moulds, old damp sand is principally used in preference to the fresh material, being much less adhesive, and allowing the patterns to leave the moulds easier and cleaner. Meal dust or flour is used for facing the moulds of small articles; but for larger works, powdered chalk, wood-ashes, and so on, are used, as being more economical. If particularly fine work is required, a *facing* of *charcoal* or *rottenstone* is applied. Another plan for giving a fine surface is to dry the moulds over a slow fire of *cork shavings*, or other carbonaceous substance, which deposits a fine thin coating of carbon. *This*, when good fine facing-sand is not to be obtained. As regards the proportions of sand and loam used in the formation of the moulds, it is to be remarked that the greater the quantity of the former material, the more easily will the gases escape, and the less likelihood is there of a failure of the casting; on the other hand, if the latter substance predominates, the impression of the pattern will be better, but a far greater liability of injury to the casting will be incurred from the impermeable nature of the moulding material. This, however, may be got over without the slightest risk, by well drying the mould prior to casting, as you would have to do were the mould entirely of loam.

For some works, where easily fusible metal is used, metallic moulds are adopted. Thus, where great quantities of one particular species of casting is required, the metallic mould is cheaper, easier of management, and possesses the advantage of producing any number of exactly similar copies. The simplest example which we can adduce is the casting of bullets. These are cast in moulds constructed like scissors, or pliers, the jaws or nipping portions being each hollowed out hemispherically, so that when closed a complete hollow sphere is formed, having a small aperture leading into the centre of the division line, by which the molten lead is poured in.

Pewter pots, inkstands, printing types, and various other articles, composed of the easily fusible metals, or their compounds, are moulded on the same principle. The pewterer generally uses brass moulds: they are heated previous to pouring in the metal. In order to cause the casting to leave the mould easier, as well as to give a finer face to the article, the mould is brushed thinly over with red ochre and white of an egg; in some cases, a thin film of oil is used instead. Many of the moulds for this purpose are extremely complex, and, being made in several pieces, they require great care in fitting. With these peculiar cases we have, at present, little to do (see

MOULDING), and shall conclude with a few observations on the method of filling the moulds. The experienced find that the proper time for pouring the metal is indicated by the wasting of the zinc, which gives off a lambent flame from the surface of the melted metal. The moment this is observed, the crucible is to be removed from the fire, in order to avoid incurring a great waste of this volatile substance. The metal is then to be immediately poured. The best temperature for pouring is that at which it will take the sharpest impression and yet cool quickly. If the metal is very hot, and remains long in contact with the mould, what is called *sand-burning* takes place, and the face of the casting is injured. The founder, then, must rely on his own judgment as to what is the lowest heat at which good, sharp impressions will be produced. As a rule, the smallest and thinnest castings must be cast the first in a pouring, as the metal cools quickest in such cases, while the reverse holds good with regard to larger ones.

Complex objects, when inflammable, are occasionally moulded in brass, and some other of the fusible metals, by an extremely ingenious process; rendering what otherwise would be a difficult problem a comparatively easy matter. The mould, which it must be understood is to be composed of some inflammable material, is to be placed in the sand-flask, and the moulding sand filled in gradually until the box is filled up. When dry, the whole is placed in an oven sufficiently hot to reduce the mould to ashes, which are easily removed from their hollow, when the metal may be poured in. In this way small animals, birds, or vegetables may be cast with the greatest facility. The animal is to be placed in the empty moulding box, being held in the exact position required by suitable wires or strings, which may be burnt or removed previous to pouring in the metal.

Another mode which appears to be founded on the same principle, answers perfectly well when the original model is moulded in wax. The model is placed in the moulding box in the manner detailed in the last process, having an additional piece of wax to represent the runner for the metal. The composition here used for moulding is similar to that employed by statue founders in forming the cores for *statues*, *busts*, and so on, namely, two parts brick-dust to one of plaster of Paris. This is mixed with water, and poured in so as to surround the model well. The whole is then slowly dried, and when the mould is sufficiently hardened to withstand the effects of the molten wax, it is warmed, in order to liquefy and pour it out. When clear of the wax, the mould is dried and buried in sand, in order to sustain it against the action of the fluid metal.

We shall examine one or two cases which come more or less within the province of the engineer. One of these is the founding of bells, a subject of much interest, as works of this kind are often of very considerable magnitude, and demand the skilful attention of the engineer. Large bells are usually cast in loam moulds, being *swept* up, according to the founder's phraseology, by means of wooden or metal patterns, whose contour is an exact representation of the inner and outer surfaces of the intended bell. Sometimes, indeed, the whole exterior of the bell is moulded in wax, which serves as a model to form the impression in the sand, the wax being melted out previous to pouring in the metal. This plan is rarely pursued, and is only feasible when the casting is small. The inscriptions, ornaments, scrolls, and so on, usually found on bells, are put on the clay mould separately, being moulded in wax or clay, and stuck on while soft. The same plan is pursued with regard to the ears, or supporting lugs, by which the bell is hung.

Brass Guns are another important branch of this manufacture. They are moulded in a manner quite distinct from any other work of this nature. The exterior surface of the gun is produced by wrapping gaskin or soft rope round a tapered rod, of a length slightly greater than that of the gun. Upon this foundation of rope the moulding loam is then applied; the surface being turned to the exact shape and proportions of the gun. A long fire is used by the founder in this process, in order to dry the mould as he proceeds in its manufacture. When perfectly dry, the surface of the mould is black-washed over, and again covered with loam to a depth of 2 or 3 in. This exterior coat of loam is secured and strengthened by a number of iron bands, and the whole is well dried. The primary mould is now completely withdrawn from the outer shell, the formation of which renders it an easy matter, as the timber rod leaves the rope with great facility, when the latter may be withdrawn, and the clay covering picked out afterwards.

The trunnions of the gun are formed separately, and attached to the shell in the ordinary way. When finished, the moulds are sunk perpendicularly in a sand-pit, near a reverberatory furnace, a vertical runner being made, leading to each mould, which it enters near the bottom. A suitable channel communicates with the furnace containing the brass intended for the guns. The metal being introduced at the bottom of the mould, no air can possibly be detained by its entrance, as each mould is full open to the atmosphere at the top.

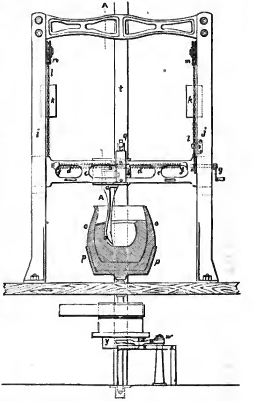
T. V. Morgan's apparatus, or machine for making large and small crucibles, is illustrated by Figs. 3002 to 3004. This important and peculiar mechanical arrangement consists in fitting the "former," or forming tool employed in the apparatus, Fig. 3002, so that in addition to being capable of an up-and-down movement, the former is free to be moved and adjusted horizontally as the crucible is being moulded, and according to the required size or thickness of the crucible; it also consists in the employment of a lever to prevent all vibration or movement of the former or shaper, when at its final position in the crucible.

The forming tool is fitted to a block free to be moved horizontally in a frame by means of a horizontally threaded rod, which takes into a corresponding female thread in the block; the ends of this rod work in fixed nuts on the frame, and one end is provided with a handle which is turned according as the former and its block are required to be moved. The frame before mentioned is free to move up and down in slots formed in two uprights, and its weight is counterbalanced. The bottom of the slots limits the distance to which the frame with the former can be lowered. When a crucible is to be made the frame is pulled down to cause the former to enter the plastic material, which is placed in a mould, on a revolving lathe, or *jigger*, as usual, and when the former reaches the bottom of its course, a catch on one of the uprights secures the frame in position. The threaded rod is then turned, to cause the former to move horizontally, and spread the plastic material against the side of the mould. Finally, the back end of a lever carried on the top of the frame, and free to move backward by means of slot or otherwise, is inserted into a hole formed for the purpose, and its forward end is pressed down by hand, so that the lever bears forcibly upon the frame, and prevents all vibration or movement of the former. When the crucible is finished, the handle is turned to bring the former to the centre of the crucible, the lever is moved forward out of its hole, the catch released, and the frame raised up by a balance-weight. The operation is then repeated for the next crucible, and so on.

This invention further consists in the employment of a brake to stop the revolution of the lathe or *jigger*, when the driving belt is moved from the fast to the loose pulley of the lathe-shaft. This brake is preferably composed of a horizontal bar hinged behind the apparatus, while one end extends to the front of the apparatus, near to the attendant. The bar carries a block, and when the brake is to be applied, the attendant, by his foot or otherwise, moves the bar on its hinge, so as to cause the block to bear against a collar or other revolving portion of the lathe.

Fig. 3002 is a front elevation; Fig. 3003 a side elevation; and Fig. 3004 a section through the line A A of Fig. 3002, of an apparatus constructed according to Morgan's improvements. *a* is the former, or forming tool; it is fitted to a block *b*, which is, as before stated, free to be moved horizontally in a frame *c* by means of a horizontal threaded rod *d*, taking into a corresponding thread *e* in a nut b^1 in the block *b*; the ends of the rod *d* work in fixed nuts *f f*, on the frame *c*, and the right-hand end is provided with a handle *g*, which is turned according as the former *a* and block *b* are required to be moved. The frame *c* is free to move up and down in slots *h h*, formed in two uprights *i*, *j*, and its weight is counterbalanced by weights *k k*, on the end of chains or cords *l l*, passed over pulleys *m m*, and connected to the frame *c*. *n* is a catch on the upright *j*, to secure the frame *c* in position when the former *a* reaches its lowest position. *o* is the mould into which the plastic material is fed; this mould is carried on an ordinary lathe or jigger *p*, to which rotary motion is imparted as usual. When the frame c is caught by the catch *n*, and the mould is caused to rotate, the threaded rod *d* is turned by its handle *g*, so as to cause the former *a* to move horizontally, and spread the plastic material against the side of the mould *o*; and when it has been moved to the required distance, which is regulated by a scale on the frame *c*, the back end of a lever *q* carried on the top of the frame *c* and free to move backward by means of a slot *r* is inserted into a hole *s* formed in an upright *t*, and its forward end is then pressed down by the attendant so that this lever bears forcibly upon the frame *c* and prevents vibration or movement of the former *a*. When the crucible is finished, the handle *g* is turned to bring the former *a* to the centre of the crucible, the lever *q* is moved forward out of its hole *s*, the catch *n* is released, the frame *c* is raised up, and the mould is removed in the ordinary manner; all being then ready for the next operation. *u* is a horizontal bar under the platform *v* and hinged at *w*, while its front end extends to the front of the apparatus. *x* is a block on the bar *u*, and *y* is a collar on the lathe-shaft. When it is required to stop the revolution of the lathe, the attendant moves the bar *u* on its hinge *w*, so as to bring the block *x* against the collar *y*. *z* is a horizontal bar or guide for the bar *u*.

3002.



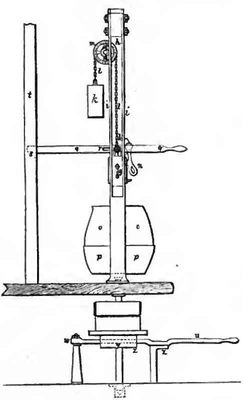
The Morgan steel crucible, Fig. 3005, so highly valued, is made of about 1 part fire-clay, and 2 of graphite or plumbago. This paste is worked to great perfection by the machine, Figs. 3002 to 3004. During the burning the Morgan crucible undergoes no change internally, as only the surface of the graphite burns.

Fig. 3006 is a section of a Morgan crucible, capacity 50 kilos., that is, a little over 100 lbs. English. The Plumbago Crucible Co., Battersea Works, London, designates this crucible No. 50.

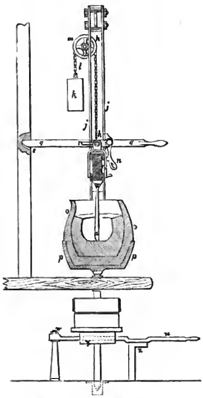
A B = 11·1 in.; B C = 1·3 in.; E F = 8·0 in.; F G = ·9 in.; and *m n* = 1·4 in.

The crucibles, Figs. 3005 to 3012, are selected from among the vast variety of crucibles manu-

3003.



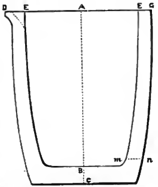
3004.



3005.

Plumbago crucible and cover for melting steel and malleable iron.

3006.



No. 50 crucible for melting gold, silver, brass, copper, and nickel. These melt on an average 40 pourings, and are made of any shape and size to hold from 1 lb. to 1000 lbs.

3007.

London clay crucible for refining gold.

3009.

Scarifier.

3010.

London clay crucible for refining gold.

3012.

Skittle pot for refining jeweller's sweep.

3008.

Crucible, cover, and whiffle for melting silver.

3011.

Roasting dishes.

factured at the Battersea Works. The crucibles of this company have been in most successful use for many years, and are now used exclusively by the English, Australian, and Indian mints; the French, Russian, and other Continental mints; the royal arsenals of Woolwich, Brest, and Toulon: and have been adopted by most of the large engineers, brass-founders, and refiners in England. Their great superiority consists in their capability of melting on an average forty pourings of the most difficult metals, and a still greater number of those of an ordinary character, some of them having actually reached the extraordinary number of ninety-six meltings. (See Crucibles.)

These crucibles never crack; become heated much more rapidly than any other description, and require only one annealing—may be used any number of times without further trouble, change of temperature having no effect on them. Mons. C. Dierick, master of the French mint, writes:—"Each crucible runs from forty to sixty pourings, and can with safety be dipped in cold water when at a red heat, and used again immediately, as if it had not undergone any change of temperature." A large amount of time is daily saved at starting, other crucibles requiring to be annealed every morning before using, whilst these, although lasting a very considerable number of heats, *only* require to be annealed *once;* the *metal* is also fused much more rapidly, saving *time, fuel, labour,* and *waste;* the saving also of *metal* is very great, as to each worn crucible there adheres a certain amount of metal—the commoner the crucible the greater the absorption and adhesion. In this respect, comparing the Morgan plumbago with the common crucible, the saving of metal and fuel is equivalent to the cost of the plumbago crucible.

This company have introduced crucibles especially adapted for the following purposes, namely;—Malleable Iron Melting, the average working of which has proved to be about *seven days;* Steel Melting, which are found *to save nearly a ton and a half of fuel to every ton of steel fused;* and for Zinc Melting, lasting much longer than the ordinary iron pots, and saving the great loss which arises from mixture with iron.

Crucibles have been in use for melting and refining metals from that distant point of time when man exchanged his stone hatchet and bone chisel for implements of bronze. The earliest melting pots were doubtless made of the plastic and infusible substance clay, and there is no reason to suppose that they differed essentially from the earthen crucibles now commonly used in our foundries.

As an instrument of scientific research, the crucible has held an important position for at least a thousand years. It was constantly used by the first alchemists, and may, indeed, be truly styled the cradle of experimental chemistry.

At the present time, crucibles of one form or another are extensively employed by the refiner of gold and silver, the brass-founder, the melter of copper, zinc, and malleable iron, the manufacturer of cast steel, the assayer, and the practical chemist. They are made in many different shapes and sizes, and of many materials, according to the purposes for which they are intended. For certain chemical experiments, requiring high temperature, vessels of platinum, porcelain, and lime, are adopted; but for ordinary metallurgical operations clay crucibles and plumbago crucibles are exclusively employed. We, in this place, confine our remarks to these two important classes of crucibles. On examining a clay or plumbago crucible it seems to be merely a rough specimen of pottery that might be easily imitated; yet the successful makers of crucibles are so few that they might almost be counted on the fingers of two hands. When we take into consideration the qualities which are required in a crucible to enable it to pass victoriously through the ordeal by fire, the paucity of good makers becomes intelligible. The crucible should resist a high temperature without fusing or softening in a sensible degree. It should not be liable to break or crumble when grasped with the tongs, and it ought to be but little affected by the chemical action of the ashes of the fuel. Again, it may be required to withstand the corrosion and permeation of such matters as melted oxide of lead. In some cases crucibles should resist very sudden and great alternations of temperature, so that they may be plunged while cold into a furnace nearly white hot without cracking. In other cases they are merely required to resist a high temperature after having been gradually heated. Some crucibles are specially remarkable for one quality, and others for another, so that in selecting them the conditions to which they will be exposed must be kept in view.

The Editor of this Dictionary, being an experienced metal-worker, speaks, for the benefit of others, without reserve; he knows from experience that the crucibles which present the finest combination of good qualities are those of the Battersea Plumbago Crucible Company. They support, even when of the largest size, the greatest and most sudden alterations of temperature without cracking; they can be used repeatedly, and their inner surface can be made so smooth that there is no fear of the particles of metal hanging about the sides. Their first cost is necessarily high, as plumbago is an expensive raw material; but the fact that they may be used for a great number of meltings makes them, in reality, cheaper than the ordinary clay pots. As fire-clay contracts considerably when exposed to a high temperature it cannot be used alone for large crucibles. The so-called clay crucibles are made of a mixture of the plaster clay with some other substance, such as highly-burnt fire-clay, silica, or coke, which counteracts in a measure the evil done to contraction, and so lessens the tendency of the vessels to crack. The large Stourbridge clay crucibles, so extensively employed by the brass-founders of Birmingham, contain both burnt clay and coke. The Cornish and Hessian crucibles are made of peculiar kinds of clay in admixture with sand. The great superiority of the plumbago crucibles over these can be easily accounted for by the fact that graphite or plumbago is the most impressible of all substances known, and at the same time a material that can be thoroughly incorporated with the clay without impairing its plasticity.

With respect to fire-clay, W. H. Stephenson, writing in the Transactions of the S. of E., observes;—Among the various deposits which have succeeded the formation of the primitive rocks upon the surface of the globe, there are certain earthy strata of very considerable extent composed chiefly of silica and alumina, partly in combination, and partly in mere mechanical mixture with other less prominent and essential ingredients. These strata are characterized by the very minute state of division of their particles, and their want of firm connection or solidity. It is to this peculiar structure that the most valuable property of clay must be ascribed—that is, its plasticity, or the property of forming dough with water, sufficiently soft to take the most delicate impression from a mould, and so deficient in elasticity that even the slightest indentation is lasting and persistent.

By far the greater number of clays are so intermingled with substances foreign to them in their original localities, or have been primarily derived from such compound species of rock, or, lastly, have been so very far removed by the agency of water from the sources of their different constituents, that it is next to impossible to trace back the course of their formation to its very commencement; although the clays may be viewed in general as the remains of certain rocks which have been decomposed by various agents, chiefly atmospheric, which have, in a word, been weathered; yet there are few cases in which the production of clay has occurred in the immediate locality of the rock whence it is derived, and in such a simple manner as to enable its origin to be traced in all particulars, and established indubitably by chemical facts.

The most prominent physical properties of clay are its plasticity and behaviour when exposed to heat. By simple drying, at a temperature far below red heat, its particles collapse, the primary pores become contracted, and a very much more dense mass is obtained, which becomes so hard that it will no longer take impressions, although it is still sufficiently soft to be cut with a knife, and when treated with water is again converted into clay with the ordinary properties.

Exposed to the most intense heat that can be artificially produced, clay refuses to become liquid, and acquires at most a slight degree of flexibility. Its particles then cohere so strongly together that the burnt mass is hard and sonorous, although still porous enough to absorb water with avidity. Although it no longer falls to pieces, but retains its connected form, it will easily be conceived that the nature of clay must be very much modified by an admixture of foreign matters possessing other properties. These foreign matters may either be constituted of undecomposed detritus of the rocks from which the clay itself derives its origin, or of others which do not belong to the class of substances which yield clay by decomposition. The character of these foreign admixtures causes great variation in the nature of the different clays, and gives rise to the various denominations by which they are known. The ingredients which most affect the quality of the clay are sand, iron, lime, and magnesia.

The plasticity of clay diminishes with the amount of any one of these substances which it contains, as they are not plastic.

The quality is affected in the most marked manner by sand, somewhat less by lime, and very little by oxide of iron. When clay contains iron and lime, the action of heat upon it is very different: the silica, alumina, lime, and iron then form together a mixture similar to that employed in the manufacture of bottle glass, which melts in the fire with more or less ease, according as it contains much or little of the two latter ingredients. Magnesia exerts less influence upon the character of the clay; the more quartz and silica enter into the composition of the clay, the less easy will it be of fusion, and an excess of iron or lime can be corrected by a large quantity of this ingredient.

Fire-clay is commonly found in the coal-measures, at a great depth from the surface, but it not unfrequently happens that it lies on the top. Stephenson's experience was with clay at some considerable depth, and lying (at Throckley, Newcastle-upon-Tyne) immediately underneath the coal formation; its thickness varies according to circumstances, in some places 3 ft., and in others reduced to 18 in. As a rule, it is very strong and hard, and cannot be worked to advantage without the aid of gunpowder. It would be needless to recapitulate the ordinary working of a coal mine; but suffice it that the clay, on being raised to the surface, is laid out in long parallel heaps, say 20 ft. high, being 20 ft. wide at the bottom, and tapering to 5 ft. at the top. A series of ridges is thus formed, purposely, however, in order to collect as much rain and snow as possible, which, combined with the direct action of the atmosphere, soon reduces that which was at one time hard and retentive, to a soft, comparatively plastic state. Difference of opinion exists among manufacturers as to the policy of adopting this system, inasmuch as to carry it out fully a very large capital is necessary, and which for the time being lies dormant.

The sole advantage accruing in keeping so large a stock is, that it is more easily pulverized and reduced to powder, thereby causing a considerable saving in engine-power, labour, and expense. To carry out this method to its fullest extent, no clay ought to be used until it has been exposed to the action of the elements for at least two years. After the clay is brought to the works, the first process is that of grinding; the most approved plan is that of two large stones, say 10 ft. in diameter and 20 in. wide, hooped all round with iron, and revolving slowly on a cast-iron pan, or bed-plate, which in some works is also made to revolve very slowly the contrary way to the stones. The rough clay from the pit being conveniently placed for the workman, is cast under the edge stones, when it is ground to a coarse powder, which falls through an open grating in the centre of the bed-plate, whence it is lifted in the sifting cylinder by an endless chain of buckets. The clay, as it passes down the cylinder, is separated into two parcels; the coarse, or that which is too large to admit of its being passed through the meshes of the cylinder, is returned by a long wooden spout to the mill, where it a second time is ground, whilst the fine particles are received into an endless belt composed of glazed sack-cloth, and conveyed into the mixing pan, or pug-mill.

Some manufacturers prefer allowing the pugged clay to lie and *sweat* for a few days in a dark place, thereby giving greater ease and facility in working, the clay being rendered of a more plastic nature by the delay. Others remove it immediately from the pug-mill to be moulded into bricks, retorts, and so on.

Brick moulds are made of various materials, some of brass, cast in four pieces and riveted together, others of sheet iron cased with wood in the two longest sides. Iron moulds are *sanded*, but not wetted. Copper moulds are an improvement on the iron, as they require neither sanding nor wetting, and do not rust; they, however, are expensive, and do not last long, as the edges wear down very fast.

The cost of moulding bricks bears so small a proportion to the total cost, that it is questionable whether the application of machinery for this purpose in small works would effect any ultimate saving; numerous inventions have been patented, but few of them can be said to have proved successful.

The moulding operation in the ordinary brick-works is simpler than is the case with any other kind of clay ware.

The workman is supplied with a stock of clay (from the pug-mill) by his side, a table or bench before him, and two boys or helpers. The mould is larger in proportion than the finished brick, owing to the contraction of the clay in drying and burning; this, of course, varies under different circumstances, the tougher and finer the clay the greater the contraction, and *vice versâ*; in general, 1 in. to the foot is the calculation for contraction, and the moulds must be made accordingly.

The usual size of a brick is 9 in. long, 4½ in. broad, and 2½ in. thick.

The mould itself only makes the four narrow sides of the brick, the one broad surface being produced by the table which supports the mould, the other by a straight piece of wood, with which the workman removes away the excess of clay, by drawing it straight along the upper edge of the mould. To prevent the clay adhering to the mould, it is from time to time damped with water, which causes the moulded brick to separate from the mould without bending or loss of time. The operation is conducted as follows:—The workman throws a lump of clay with great force into the mould before him; the mass, which has become flattened by the shock, is forced into the corners by one or two rapid strokes with the hand, and that which projects beyond the mould is taken away with the flat board. By a sudden and peculiar twist of both hands, the workman deposits the brick from the mould on to a thin board previously placed before him for the purpose; one of the boys in attendance immediately places another similar board on the top of the newly-made brick, and thus carries it away between these two boards. Meanwhile, another brick is made as described, and thus the process continues during the hours of labour. The bricks are placed in long rows edgeways on the dry flats, a space equal to the thickness of the board, say ½ in., being left between each brick, in order to give vent to the steam generated in drying.

The drying sheds or flats consist of long floors, say 90 ft. by 30 ft., with flues running the whole extent of the building. It is desirable not to have the length of these flues more than, say, 40 ft., in order to ensure a good draught without any additional coals being used.

In most manufactories these drying flats are so constructed that there is ample room or accommodation for two days' work; in this case the moulders are never stopped, and are not required to remove their tables or benches from place to place. From thirty-six to forty-eight hours is calculated quite sufficient for drying bricks; so that while the moulder and his boys are depositing bricks on one part of the flat a gang of men and boys are engaged in clearing away the bricks from another part.

The number of bricks which a workman can mould in a day of ten hours is always considerable, but depends much upon the ability and strength of the moulder. With clay in good order a skilled workman can make 2000 to 2500 marketable bricks in a day.

It is clear that the relative merits and value of fire-bricks depend upon their fire-resisting qualities, and hence depend upon the proportion of silica they contain.

In an analysis of several kinds of Newcastle clay, Dr. Richardson found—

Nos.	1.	2.	3.	4.	5.	6.	7.
Silica	51·10	47·35	48·55	51·11	71·28	83·29	69·25
Alumina	31·35	29·50	30·25	30·40	17·75	8·10	17·90
Oxide of iron	4·63	9·13	4·06	4·91	2·43	1·88	2·97
Lime	1·46	1·34	1·66	1·76			
Magnesia	1·54	0·71	1·91	trace	2·30	2·99	1·30
Water and organic matter ..	10·47	12·01	10·67	12·29	6·24	3·64	7·58

whilst the amount of silica in No. 6 is to the total amount of the bases as 100 : 16, in No. 2 it is as 100 : 85. These clays are mixed in different proportions, according to the object of the manufacturer.

When, therefore, it is desirable to procure a first-class article, a chemical analysis, although it cannot supersede an actual trial, may be of the greatest service, as the clays seldom or never come up to what is required of them, and only acquire the requisite properties by certain additions, and the choice of these additions must, in the first instance, be guided by the results of the chemical analysis; such additions are absolutely necessary, as fire-clay must not only be infusible in the fire, but must likewise not be subject to crack and fly. These properties are most important. The chief cause of the cracking, or the contraction of the clay, must therefore be lessened by the addition of substances which do not shrink themselves, and, on the other hand, do not impair the refractory nature of the clay.

Pure sand and previously-burnt fire-clay are the substances most commonly and appropriately used.

The Process of Fire-clay Retort Making.—Referring to the period when the fire-clay has been drawn from the mine and undergone the process of weathering, that which is intended for retorts has been kept separate for that purpose, while greater care and attention has been bestowed on it, in order to pick out any pieces of coal or iron with which it may have been associated. This, although seemingly an insignificant, is a very important part of the manufacture, inasmuch as a very small piece or particle of ironstone is sufficient to damage and spoil a whole retort, and thereby occasion considerable loss.

The clay having been thus thoroughly examined and approved, is next ground in a similar manner to ordinary fire-brick clay, excepting that the particles are not ground so fine (the average size of the meshes through which the clay passes for bricks is, say 5 × 6 to the inch, whereas for retorts it is as large as 3 × 4 to the inch), and in order to render the retorts porous, a proportion of coke or sawdust, say ⅓ to ¼ the weight of the whole, is added to the fire-clay, and mixed up with it, both in the grinding and pugging process. The pug-mill, through which this retort clay passes, is generally longer and wider than the ordinary brick-clay pug-mill; or, instead of this, it is not unusual to pass the clay through two pug-mills, the one delivering into the other, so as to ensure the clay being well worked and of a proper consistency.

The manufacture of *clay retorts* was formerly carried on by machinery, but now the same objection may be said to exist against this method, as is the case with regard to machinery for brick-making. The result has, therefore, been that retort-making by hand has now become the rule, and by machinery the very rare exception.

The hand building is performed by small lumps of clay being pressed against the side of a mould or drum the required shape, and this continued till a height of 8 in. or 10 in. is obtained, the walls being gradually built up according to two wooden guides, the one of which indicates the thickness, say 2½ in. to 3 in., the other the outward shape of the retort.

Some clays are more plastic than others, and will consequently bear a higher or longer building, but in general 9 in. are sufficient at once, in order to ensure soundness and firmness. This process of building is continued every day, or as often as necessary, till any length of retort is obtained, the top end always being kept perfectly moist, to guarantee perfect adhesion throughout the whole. The flats or sheds in which these retorts are made, are constructed in like manner to the brick flats, excepting that more height is allowed from the level of the floor to the joists, to contain the longest retorts. Fires are constantly kept burning under the floor on which the retorts are being built, and this process of drying is perhaps one of the most important of the manufacture. If not carefully and properly dried, cracks will show all over the surface, the colour of the fracture will not be uniform, and the retorts essentially bad.

It was stated that coke and sawdust were mixed with the clay in order to make the whole mass porous. To provide against the porosity of the retorts causing a loss of gas, a composition or mixture composed of about equal parts of unburnt and calcined fire-clay finely pulverized, with the addition of as much water as renders it a consistency of thick *paste*, is applied day by day to the internal and external surfaces of the retorts, and well worked in (by the hand) to the body of the retort; thus an even, smooth, and unbroken surface, free from cracks and flaws, is produced, and the retort presents a uniform appearance throughout.

The burning of the retorts requires much care and attention, and generally continues for a period of ten to twelve days. The retorts being placed vertically on rows of bricks on the bottom of the *kiln*, the great desideratum is to procure a steady draught, the exclusion of atmospheric air, and a gradually progressive heat.

Opinions differ very widely as to the best shape of clay retorts, the circular, oval, or elliptical, and ⌓, being those commonly advocated and in use, while the egg-shaped, or combination of round and oval, and the round curved ⬭ have each their supporters. In the leading metropolitan works the 15 in. round, and 21 in. × 15 in. oval, in settings of five and seven retorts in a bench, appear to be in favour; these retorts being from 18 ft. 6 in. to 20 ft. in length (open throughout, and charged at each end), are constructed in three or four pieces to suit convenience.

The comparative merits of clay and iron retorts is a subject which has attracted much attention from the gas engineering profession during the past few years. The results of numerous practical trials, comparing their relative durability, economy, and carbonizing power, have from time to time appeared in the various serials devoted to the gas-light interest, and many facts worthy of attention have been elicited by the controversy respecting their comparative excellence. It may seem a matter of much surprise to those unacquainted with the details of these practical essays, that a substance apparently so friable and brittle in its nature as clay should have superseded cast iron to a great extent, and received the highest encomiums from nearly every responsible source. Yet such has been the case, and this important reform, which but a few years ago met with many obstructions, in having to withstand a rigorous prejudice, has lately been gaining ground with great rapidity, and promises ere long to meet with universal approbation.

Brass Founding.—Pure copper is moulded with difficulty, because it is often filled with flaws and air-bubbles, which spoil the casting; but by alloying it with a certain quantity of zinc, a metal is obtained free from this objection, harder, and more easily worked in the lathe. Zinc renders the colour of copper more pale; and when it exists in certain proportions in the alloy, it communicates to it a yellow hue, resembling that of gold; but when present in larger quantity, the colour is a bright yellow; and lastly, when the zinc predominates, the alloy becomes of a greyish white. Various names are given to these different alloys. The one most used in the arts is *brass*, or *yellow copper*, composed of about ⅔ of copper and ⅓ of zinc. Other alloys are also known in commerce, by the names of *tombac*, *similor* or *Mannheim gold*, *pinchbeck* or *prince's metal* (chrysocale), &c.; they contain in addition greater or less quantities of tin.

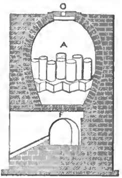
Tombac, used for ornamental objects which are intended to be gilded, contains 10 to 14 per cent. of zinc; the composition of *Dutch gold*, which can be hammered into very thin sheets, being nearly the same. Similor, or Mannheim gold, contains 10 to 12 per cent. of zinc, and 6 to 8 of tin; and pinchbeck contains 6 to 8 per cent. of zinc, and 6 of tin. The statues in the park of Versailles are made of the following alloy;—

Copper	91	Tin	2
Zinc	6	Lead	1

The alloys of copper and zinc are altered by a high temperature, and a portion of the zinc is volatilized. If brass be heated in a brasqued crucible in a forge-fire, the zinc is nearly wholly driven off.

Brass is made by melting directly copper and zinc; rosette copper being used, fused in a crucible, and run into water to granulate it. The zinc is broken into small pieces. The fusion is effected in earthen crucibles which can contain from 30 to 40 lbs of alloy, the metals being introduced in the proportion of ⅔ of copper and ⅓ of zinc, to which scraps of brass are added. A certain number of crucibles are placed in an egg-shaped furnace A, Fig. 3013, lined with refractory bricks, and supported by a brick dome, having apertures through which the flame of the fuel passes, the grate F being immediately beneath the dome. The crucibles are introduced through the upper opening of the furnace, which is covered during the smelting by a lid having a hole O for the escape of the gases. A register beneath the grate regulates the draught, and serves for the extraction of the crucibles. When the alloy is fused, the crucibles are removed with tongs, and the brass run into clay moulds; and sometimes it is run between two very smooth slabs of granite, kept at a proper distance from each other by iron rods.

3013.



Small quantities of lead and tin are frequently added to brass to make the alloy harder and more easily worked; brass which contains no lead soon *chokes* a file, which defect is remedied by the addition of 1 or 2 hundredths of lead.

Copper and tin mix in various proportions, and form alloys which differ vastly in appearance and physical properties, as tin imparts a great degree of hardness to copper. Before the ancients became acquainted with iron and steel they made their arms and cutting instruments of *bronze*, composed of copper and tin.

Copper and tin, however, combine with difficulty, and their union is never very perfect. By heating their alloys gradually and slowly to the fusing point, a large portion of the tin will separate by eliquation, which effect also occurs when the melted alloys solidify slowly, causing circumstances of serious embarrassment in casting large pieces.

Different names are given to the alloys of copper and tin, according to their composition and uses; they are called *bronze* or *brass*, *cannon-metal*, *bell-metal*, *telescope-speculum metal*, &c. All these alloys have one remarkable property; they become hard and frequently brittle, when slowly cooled, while they are, on the contrary, malleable when they are plunged into cold water, after having been heated to redness. Tempering produces, therefore, in these alloys an effect precisely opposite to that produced on steel.

When alloys of copper and tin are melted in the air, the tin oxidizes more rapidly than the copper, and pure copper may be separated by continuing the roasting for a sufficient length of time.

The following are the principal alloys of copper and tin;—

Cannon-metal, which in France is thus composed;—

Copper	100	90·09
Tin	11	0·91
	111	100·00

Bell-metal, which contains;—

Copper	78
Tin	22
	100

Cymbal and tam-tam metal, composed of;—

Copper	80
Tin	20
	100

Telescope-speculum metal, made of;—

Copper	67
Tin	33
	100

Bronze for medals varies slightly in its composition, and generally consists of;—

Copper	95
Tin	5
Zinc	some thousandths.

Bronze used for the manufacture of ornamental objects generally contains larger quantities of zinc. A portion of the small French coin is made of alloys of copper and tin; and although the red sous consist of nearly pure copper, the yellow sous coined under the Republic, from a metal obtained by melting the bells, contain on an average 86 of copper and 14 of tin.

Cannon Casting.—Gun-metal must fulfil several important conditions. It should be very tenacious, that the pieces may not burst under the enormous pressure caused by the explosion of the powder, while it should be sufficiently hard not to be injured by the ball, which strikes the sides several times before leaving the muzzle; and, lastly, it should be fusible, because large guns can only be made by casting.

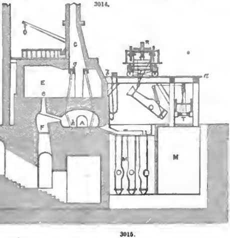
Copper and iron are the only metals which possess sufficient tenacity; but as pure iron will not fuse very readily, it is necessary to substitute for it cast iron, the tenacity of which is much inferior. Copper possesses great tenacity, but is too soft; and in rapid service would soon be so battered as to be useless. Recourse must then be had to alloys of copper with other metals; and long experience has shown that alloys of copper and tin are the most suitable; but as, while tin greatly increases the hardness of copper, it diminishes its tenacity, it becomes necessary to stop at certain proportions of the two metals, at which the alloy possesses both the requisite degree of hardness and tenacity. These proportions, which have been determined by numerous experiments, made at various times and in different countries, have been fixed at 11 of tin for 100 of copper. It has, however, been ascertained that for pieces of a calibre below 8, an alloy of 8 or 9 per cent. of tin is preferable. Many experiments have also been made to ascertain if the alloy could not be improved by the addition of other metals, as zinc, iron, or lead; but these complicated alloys have all been rejected, on account of the great variation of their results; and pieces were frequently rendered useless in consequence of the difficulty of obtaining such alloys homogeneous and of uniform composition.

The use of cast iron for the manufacture of cannon is long subsequent to that of brass. As it is cheaper, it might be very advantageously substituted for bronze, but it is very brittle, and pieces of the same calibre must be much thicker than of the latter metal, thus becoming too ponderous for field service. They are well adapted to stationary batteries, fortifications, coast defence, and ships of war. Cast-iron guns ring much less than those of bronze, and for this reason are preferable on board of ships, where brass pieces, on the lower-deck batteries, would make a noise insupportable by the gunners. Very soft cast iron, made with charcoal, should alone be used for artillery; and some of the Swedish iron is highly valued for this purpose.

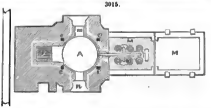
The furnaces in which bronze is melted should contain no oxidizing gases, and the atmospheric air traversing them should be deprived by combustion, as far as possible, of its oxygen, because the tin, which is more oxidizable than copper, would constantly separate from the alloy in the form of oxide, and the composition of the bronze, at the time of casting, would not be known with certainty.

Figs. 3014, 3015, represent a melting furnace, used in the cannon-foundry at Toulouse. It is a circular reverberatory furnace A, with a surbased dome, heated by the grate F, on which small billets of wood are burned. The wood being charged through the opening *o*, a thick layer of fuel is heaped on the grate, in order that the atmospheric air, which does not enter the furnace until it has passed through the fuel, shall be completely deprived of its oxygen. The draught is regulated by four elongated working holes *h*, *h*, arising from the hearth-sole, and terminating at the vent-holes *e g*, *e g*, which open into the chimney C, by means of which arrangement the flame is obliged to spread over the metallic bath which covers the hearth-sole. Near the furnace are cavities M M′, lined with cement to preserve them from dampness, and in which the moulds are placed, and kept firm by heaping earth around them. The moulds, which are made of clay, cow's-hair, and horse-dung, intimately mixed, are fashioned on a model in relief, partly of earth and partly of plaster, which is destroyed when the mould is finished, and strengthened by iron bands or loops. Above the mouth of the gun is a prolongation, called the *masselotte*, or lump, the use of which will soon be explained. The moulds, after being baked at a high temperature, so as to dry them as much as possible, are fixed in their places, the breech being downward. Between the tap-hole *i* and the moulds, canals are made which convey the liquid bronze into each mould; and above is a railway *a b*, with a car R, containing a capstan, by means of which the moulds, when filled, can be lifted out and carried away.

3014.



3015.



Moulding sand, so well adapted to the moulding of cast iron and other metals, has been substituted for the earth with which the moulds are made, but never with success, as the walls of the sand mould are too compact and too impervious to gases. Now, immediately after the casting of bronze, the metal disengages numerous gaseous bubbles, which pass through the porous walls of the mould, and present less resistance than the high column of melted metal; while in the sand moulds, the gases not being able to escape through the sides, produce a constant bubbling in the mass, giving rise to numerous flaws, and assisting the separation, by eliquation, of the tin, or alloys rich in tin.

The charge of a furnace is composed of old brass, chiefly condemned cannons, and masselottes taken from pieces previously cast, with brass turnings taken from the lathe or the boring machine, and a certain quantity of new metals, copper and tin, besides *white metals*, or alloys very rich in tin, which separate by eliquation in the moulds. The proportions of copper and tin in the several components being determined by analysis, they are mixed in the proportion of 100 copper to 13 or 14 tin, which is reduced by oxidation of tin in the furnace to the normal proportion of 100 : 11.

The condemned cannons and masselottes are laid on the hearth-sole, near the bridge, where the temperature is highest; while the copper, which should be very pure, in bars, and the turnings, are placed thereon, the white metals and tin being added at a later period. In six or seven hours the mass is almost entirely fused, and the flame escapes by every avenue. The smelter first stirs the material with sticks of very dry wood, and draws the portions which are not melted toward the bridge; after which he completes the charge by adding the white metals and tin, which he runs in the form of pigs into different parts of the bath. He stirs it a second time, in order to render it homogeneous, and, after skimming off the superabundant scoriæ, closes the door of the furnace, and blows up the fire, to bring the alloy to a proper state of liquidity, stirs and skims it a third time, and then opens the tap-hole. Other workmen direct the melted metal into each mould.

A remarkable phenomenon ensues in a few moments after the casting. A bubbling takes place in the upper part of the mould, proportioned to the size of the piece and the elevation of temperature, and a portion of the bronze rises in the form of a mushroom, being an alloy much richer in tin than the cast metal. A partial eliquation therefore takes place during the cooling, which causes the separation of an alloy more fusible, and containing more tin. The composition of the piece itself is not uniform, as the proportion of tin diminishes from the breech to the upper part of the masselotte. The intention of the masselottes is, not only to exert considerable hydrostatic pressure on the lower strata of the piece, but also to furnish metal necessary to compensate for the contraction of the metal by cooling, and its loss of substance by eliquation.

Twelve hours after the casting, the earth is cleared away in order to hasten the cooling of the moulds; and the latter are removed after forty-eight hours, broken, and the cast guns carried to the boring and turning shops.

When the surface of the piece is turned, and it has been bored to a certain point, it is examined to ascertain if it be free from such defects as would render it unserviceable. Such defects are various, and called by different names; but they are nearly all produced by eliquation of the tin or very fusible alloys.

Flaws, or *bubbles*, are cavities with smooth surfaces, produced by bubbles of gas which have been unable to escape; while *honeycombs* are cavities with rough surfaces, arising from irregular distribution of the materials or badly-proportioned alloy; and *worm-holes* are similar, but smaller, cavities. *Cendrures* are owing to impurities in the alloy, remaining in the metal, or detached from the sides of the mould; and *tin-spots* are produced by small, very hard masses of an alloy containing 20 or 25 per cent. of tin, which became separated by eliquation, and were unable to ascend as far as the masselotte. *Blasts*, or *cracks* (sifflets), which are longitudinal or transverse grooves, sometimes extending through the whole thickness of the piece, are likewise owing to a separation of the tin.

If the piece is found to be perfect, the boring and turning are completed, and it is subsequently examined and proved according to the regulations of the service.

Tinning of Copper and Brass.—The use of copper and brass for culinary purposes is dangerous, on account of the ease with which copper, on oxidizing by contact with the air and acid substances, forms very poisonous salts, unless the vessels are lined with a coat of tin, which prevents the liquids from coming in contact with the copper. The tinning of copper is effected by cleansing the pieces with chlorohydrate of ammonia, and spreading, with a piece of cloth or tow, melted tin over their surface when properly heated. The tin thus adheres to the copper, and covers it completely.

Pins are made of brass wire, and whitened by being covered with a thin coat of tin by the humid way. The pins are first cleansed by heating them in a solution of cream of tartar, and then placed in a copper basin with a solution of cream of tartar and tin. The liquid is boiled for about one hour, when the tin dissolves in the cream of tartar with disengagement of hydrogen gas, and is precipitated on the brass of the pins, covering them with a very thin pellicle of metal.

The Apparatus for Moulding Toothed Wheels, invented by G. L. Scott, Figs. 3016 to 3026, is designed to supply the means of obtaining accurate castings by machine moulding, with a portable and self-contained machine of small cost, capable of being readily and quickly applied at any part of a foundry.

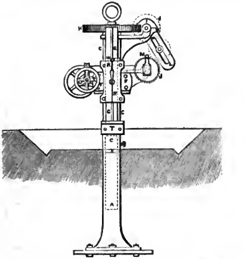
The accuracy and perfection of the teeth of wheels are of great practical importance in all cases of gearing, and especially where large amounts of power are transmitted by them; and it is requisite that the transmission of power should be uniform and continuous through the teeth of the wheels, corresponding to the continued frictional contact of two circles rolling upon each other. To maintain this uniform and continuous action in toothed wheels, all the teeth throughout the circumference of the wheel are required to be precise duplicates of one another in form, size, and spacing; and all to be placed in a perfect circle round the centre of the wheel. Should these conditions be imperfectly carried out, the essential continuous contact will be destroyed, and a serious intermittent knocking between the teeth will be caused, leading to the fracture of the wheel, and risking a stoppage of the machinery. Any defective fitting of toothed wheels also involves a waste of driving power from the irregular shocks in transmitting the power; and as a consequence the wheel will not last so long in such a case, owing to the friction causing extra wear of the teeth.

In the earliest method of making toothed wheels, the teeth were chipped out by hand from the solid edge of the wheel, upon which they were set out and shaped to template. Subsequently the teeth were formed on a wood model of the wheel, and moulded from this model according to the plan in general use, involving the necessity of having a separate expensive pattern for each wheel that differs in form and pitch of teeth as well as in diameter. The result has been a vast collection of tooth-wheel patterns to meet the requirements of ordinary trade demands; and this stock has become so costly in the expense of construction and of the storage space occupied, that it has led to an objectionable limitation in the range of pitch of wheels, in order to reduce the extent of the stock of patterns. The use of wood patterns for entire wheels involves further the practical objection of liability to distortion, both in the general contour of the wheel and in each tooth, owing to the irregular effects of expansion and contraction in the component parts of the pattern, as well as the unavoidable risk of variation in the forms and dimensions of the several teeth, in consequence of the different finish that each receives. The uncertainty, too, attending the drawing of an unwieldy pattern from its mould, and the distortion of the pattern that occurs from its lying in damp sand for a considerable time, are additional obstacles to the manufacture of a toothed wheel from the ordinary wood models with the correctness that is desirable.

The only method of overcoming these difficulties is by employing only a small segment as the pattern, and moulding the entire toothed circumference by repetition of this small portion; employing mechanical means for lowering and raising it, and for spacing out the teeth round the circumference of the wheel, so as to obtain the same certainty of accuracy throughout as is shown by a wheel divided and cut in a machine.

The machine, Fig. 3019, is of two sizes, one for moulding wheels from 12 in. to 5 ft. diameter, and a larger size for wheels from 20 in. to 12 ft. diameter. The smaller machine is shown in Figs. 3016 to 3026. Fig. 3016 shows an end elevation of the machine, Fig. 3019 a side elevation, and Fig. 3020 a plan.

3016.



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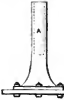
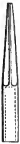


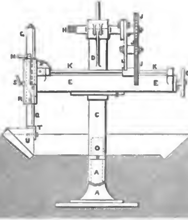
3018.



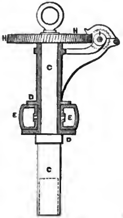
A pedestal A, Fig. 3017, supports a centre pin B, which has a collar to bear upon the pedestal, and is provided with a projection that fits into a recess in the top of pedestal, whereby it is prevented from turning in its socket. The spindle C is bored to fit on the centre pin B, and is turned to pass up through the rest of the apparatus, which it supports, as shown in section in Fig. 3021. Set screws placed in the spindle C are used to fix it firmly on the centre pin B, and this being secured in the pedestal, a continuous vertical centre spindle is thus obtained. Loose collars provided with set screws, and bored to fit the centre pin B, are used for the purpose of elevating the apparatus above the pedestal A, in order the more readily to adapt it for moulding different breadths of wheels. One of these collars is shown at V in Fig. 3026, and they are of 1, 2, and 3 in. in thickness respectively.

On the spindle C is carried the head D, shown in section in Figs. 3021, 3022, and in this head slide the radial arms E E, connected together at their front ends by the transverse piece F, which forms the bed for the vertical sliding ram G. The arms E E are secured to the head D in any required position by four square-headed bolts passing through slots in the arms and through ears cast on the head; these bolts being screwed up bind the arms and head firmly together. The spindle C being firmly secured in the pedestal forms a stationary centre pillar for the machine, on which the head D is free to turn; and on the top of the spindle is keyed the worm-wheel H, from which a connection is made to the arms E by the dividing apparatus, shown in Figs. 3016, 3019, and 3020. This consists of a worm I gearing into the wheel H, and the change wheels J J J, the uppermost wheel being on the worm-shaft and the lowest one keyed on the shaft K, which is carried by brackets on the arm E, and is provided with a loose collar acting as a bearing, so that the shaft

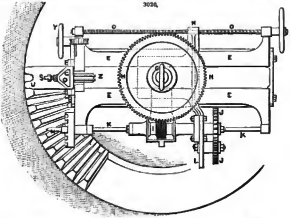
3019.



3021.

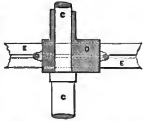


3020.



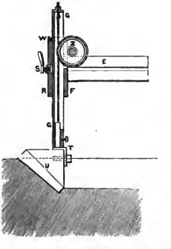
may be withdrawn for altering the change wheels when required. The swing frame L carrying the change wheels is sufficient for two intermediate change wheels if required. On the shaft K is fastened a spring handle M, which fits a slot in a disc that is divided to guide the workman in the number of turns to be given to the shaft. The traversing screw O is carried by brackets on the arm E, and passes through the nut N bolted to the head D, so that by turning the screw O by the hand-wheel at the end the arms are moved in or out, to suit the varying diameters of wheels to be moulded.

3022.

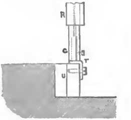


On the slide-bed F fits the vertical sliding ram G, which is held in by the cover R, shown in section in Fig. 3023; and a hand-screw S retains the ram in any required position. The bottom of the ram is bored to receive the angle-bracket T, which is secured in it by steady pins; and to this is attached the segment pattern U in the wheel-teeth to be moulded. The ram is moved up or down by a hand-wheel Y, having a worm gearing into a worm-wheel, on the shaft of which is a pulley Z; from this pulley two chains pass in opposite directions, the one being secured to the bottom of the ram and the other to the top, and kept always tight by means of two lock-nuts. An adjustable brass collar W is fitted on the ram, for indicating to the moulder when the ram is sufficiently lowered. An eye-bolt is fixed on the top of the centre pillar C of the machine, for attaching the foundry crane in order to remove the machine.

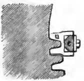
3023.



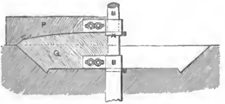
3024.



3025.



3026.



The process of moulding a wheel with this machine is as follows. A core box for the arms of the wheel is first prepared, and also two radial boards for strickling the form of the top and bottom of the wheel in the sand, which are shaped to the profiles of the face and back of the wheel. The top board P, shown in Fig. 3026, has on its lower edge the profile of the back of the wheel; and the bottom board Q has also on its upper edge the counterpart profile of the back of the wheel, and on its lower edge the profile of the face. A pattern is also made of a segment of the toothed rim of the wheel, consisting of two teeth only, which permits of moulding one space at a time.

A secure and steady foundation for the moulding machine is obtained by sinking in the sand of the foundry floor in the desired situation the pedestal of the machine, which is bolted to a cast-iron base-plate about 4 ft. square; sand is then rammed solidly upon it, and the pedestal levelled so as to be truly vertical. Another form of pedestal is shown in Fig. 3018, which is used for fixing in the sand without a base-plate. The top of the pedestal is placed about 15 in. below the floor level, this distance determining the greatest breadth of wheel that can be moulded. The centre pin B of the machine is then placed in the socket of the pedestal, for the purpose of forming the mould for the bed of the wheel, and also to mould the top box or other arrangement used to cover the mould for casting; the rest of the machine being laid aside for the present.

In Fig. 3026 is shown the loose collar V which is placed upon the centre pin B, of such thickness that its upper face is the same depth below the floor level as the breadth of the rim of the wheel to be moulded; so that the back of the wheel is level with the floor, for convenience of fitting the top box on. This lower collar V is fixed by a set screw, and an upper loose collar X is also fitted on the centre pin B by a set screw, with its upper face at the same height above the collar V as the breadth of the rim of the wheel; the lower collar thus exactly indicates the level of the bed and face of the wheel, and the upper collar that of the back of the wheel. The hole is then filled up with sand to the level of the upper collar; and the iron trammel carrying the top board P is placed upon the spindle B, and worked round upon the collar X, forming a mould of the back of the wheel, which is then sprinkled with parting sand to form the parting for the top box. An ordinary top box or other sufficient covering is then placed on, and rammed up with sand; and the box is then staked in the ordinary manner, for the purpose of marking its correct position relatively to the bottom part of the wheel, by stakes driven into the sand and fitting by the side of corresponding ears upon the top box. The top box is then lifted off, carrying with it the impression of the back of the wheel, which impression is finished by turning the box over, and strickling it again with the second trammel that carries the bottom board Q. A centre is provided in the top box for this trammel, by means of a loose collar, in which are two bolts that pass through the top box and are fastened across the bars of the box. This loose collar fits the spindle B, and is drawn from it with the top box, thus fixing a strictly accurate centre. By this arrangement the centring collar can be readily fixed upon any ordinary top box, giving strict accuracy in the moulding, without requiring any special boxes for the purpose.

For forming the bed of the mould the top collar X is then removed, and the mould being dug out to the level of the bottom collar V, the sand is strickled with the bottom radial board Q, worked round upon the bottom collar V. This forms the mould for the lower and outer faces of the teeth, and finishes the mould ready to receive the teeth and the cores for the arms; and as both the back and the face of the wheel have been struck from the same trammel and the same centre, accuracy is ensured in the wheel.

The segmental pattern of the teeth U, Figs. 3024, 3025, is then fitted truly square and central and secured by screws upon the angle-bracket T of the vertical sliding ram G, Fig. 3019. The upper portion of the machine is then placed upon the spindle B, the trammel having been removed; and the fixing screws in the spindle are screwed up, to maintain the central axis continuous through the machine. The segmental pattern U is adjusted by the traversing screw O, Fig. 3020, to the correct radius of the wheel, measuring from the top of the tooth to the centre of the machine. The ram G is then lowered to the level of the bed of the wheel, and secured at that point by the locking screw S; and the brass collar W is adjusted on the ram and fixed by a set screw, to ensure the ram always stopping at the same level, when lowered for moulding each successive tooth. The locking screw S prevents the ram rising from the pressure of ramming the sand. One space of the wheel-teeth is then moulded by ramming sand in the space left between the pattern and the edge of the mould previously formed by the strickle-board. The locking screw S being released, the ram carrying the pattern is raised clear of the mould, and is traversed round through the exact distance of the pitch of the wheel, by means of the dividing handle and the change wheels previously arranged for the required pitch. The segmental pattern is again lowered, and a second space moulded as before.

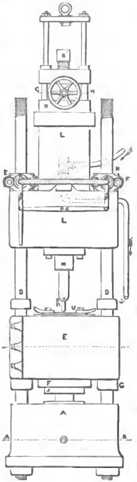
When all the teeth have been moulded, the fixing screws of the centre spindle are released, and the whole machine is then lifted away by the foundry crane laying hold of the eye-bolt on the top of the spindle, leaving the mould entirely clear to receive the cores for the arms and boss. The hole in the top of the pedestal is fitted with a cover to keep out the sand, and is then covered over with sand, which protects the pedestal against the action of the hot metal. The centre core for the wheel is adjusted as usual from the circumference, and the cores for the arms are set to their places by means of wood gauges showing the thickness of the arms and rim. The top box is then put on, to cover the mould, being placed in its correct position by the stakes; the runner is formed, the box duly weighted, and the whole is ready for casting.

Whitworth's Apparatus, Figs. 3027 to 3037, for subjecting steel to a high pressure during the process of casting. In casting some articles, such as hoops and other hollow forms, Whitworth, when using rams arranged to give a pressure to the melted metal in the mould, after applying the pressure for some time, and when the mass has become solidified, withdraws the internal resisting instrument, or core, to allow the metal to contract freely in cooling. In forming other articles, such as those of considerable length, Whitworth applies the pressure to the outer surfaces of the mould, and makes the latter in sections, between which dried loam or sand is placed, so as to allow the air to escape, and to permit of the sections being brought closer together. The object of Whitworth is to obtain sounder castings, and to do away with the necessity for great "heads" of metal.

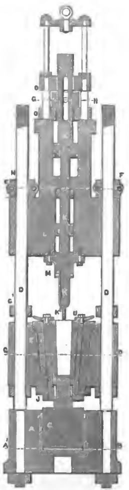
In our illustrations, Fig. 3027 shows an elevation, and Fig. 3028 a vertical section, of the apparatus. Figs. 3029 to 3032 are horizontal sections, at the lines A B, C D, E F, and F G, in Figs. 3027, 3028, respectively. In the figures just mentioned, A is a cast block, having in its centre a cylinder B of steel, within which a plunger C works; this plunger, when water or liquid is forced into the cylinder B, raising the ram Q. D D are two screw-columns, the lower ends of which are securely fixed through the casting A, whilst the upper parts above A have threads formed upon them, so that the cast block E may be supported in any desired position upon them by means of screw-nuts, G, G, G^1, G^1. The mould E F is of steel, in order that it may be of sufficient strength to sustain the great pressures to which it is subjected. This steel mould is secured in the casting E by a screw-nut F^1; within the mould is a filling piece J, which is of cast iron, and is securely retained by a nut J^1. Within the filling piece J is the lining H, of cast iron, perforated with numerous holes to facilitate the passage of air and vapour, or gases; and at the outer surface of this lining are numerous grooves, in order that the air and gases, as they pass through the perforations, may get away freely. The interior of the perforated metal lining H has a lining of sand, loam, clay, or other refractory material, which is moulded in the metal lining to the required form, and is then dried and put into position to receive the melted steel. The metal lining H is retained in its place by the turn-buckles or stops U U, and the casting E is arranged to turn on one of the screws D D as on an axis, so as to come outside the press when it is desired to remove the article from the mould, and when introducing a fresh mould into position. K is a core, which is of metal, and is coated with sand, loam, or other suitable refractory material; the coating is formed separately from the metal core, and dried, and is then placed on the metal core, and is retained in its position by pins, together with the lower nose K^2 of metal, as shown. The upper end of the stem of the metal core K is fixed into the bar K^1, which is fixed in the under-side of the piston R, the latter working in a hydraulic cylinder formed at the upper part of the iron block or casting L.

The stem of the core K is capable of sliding through the tubular plunger M, fixed, as is shown, to the casting L, and the lower end of this tubular plunger is formed of steel, and is faced with sand, loam, or other refractory material. It closes on the melted metal in the mould when the casting L is lowered, and resists the passing away of the metal when the pressure of the ram Q of the plunger C is applied to the bottom. The upper cylindrical part of the casting L is hooped with steel, and when of considerable dimensions it may be lined with a cylinder of steel. The piston-rod R^1 of the piston R has a screw-thread cut on its outer surface for the purpose of adjustment, according to the length of the core K required; and O O are two collars, secured, as is shown, to the upper or cylindrical part of the casting L. The piston-rod R^1 is capable of sliding freely up and down through the holes in the collars O O, except when locked by the screw-clip N^1. The block or casting L is also, when not locked by the screw-clips N N, capable of being raised or lowered on the upright screws D D. The screw-clips N N and N^1 are each in two parts, which are capable of being moved to or from each other by left and right handed screws on the shafts P P and P^1. The screw-shaft P^1 passes through the slot in the hollow piston-rod R^1; and against each side of the bearing p^2, on the casting L, it has two collars, p^1 p^1, fitted on it, which prevent it being moved laterally through the slot. On the screw-shaft P^1 is a hand-wheel, by which that shaft is turned, and by which the two parts of the screw-clip N^1 N^1 are caused to separate or come together, and when together to lock the piston-rod R^1, and prevent it moving through the collars O O. The left and right handed screw-shafts P have pinions P^2 fixed upon them, these pinions gearing with two wheels P^3 P^3, as shewn. The wheels P^3 P^3 turn on axes fixed to one of the two parts of which each screw-clip N N is formed, the outer ends of these axes being connected together by a bar, as shown. To each of the wheels P^3 a lever P^4 is fixed; these levers are connected by a rod P^5, having its ends jointed to them, so that when one of the two levers P^4 is moved, it, by the connecting rod P^5 gives motion to the other lever, and consequently both their wheels are simultaneously rotated, and the two wheels in their turn give simultaneous motion to the screw-shafts P, by means of their respective pinions. It is preferred that the block or casting L, and the parts connected with it, should be raised and lowered as required by hydraulic power, but they may be moved by other apparatus attached to the eye-bolt S. In the arrangements shown, the pouring of the melted steel or iron into the mould is intended to be performed before the core is introduced into the mould, and this is desirable where the sides of the hollow casting are comparatively thin, as is the case in casting hexagon shells; but where the sides of the hollow article to be cast are of greater thickness, and where the pouring of the melted metal may be freely performed after the core is in its place in the mould, the core may be introduced into its position before pouring.

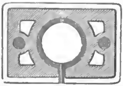
3027.



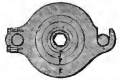
3028.



3029.

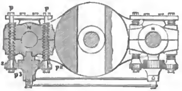


3030.

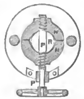


In using the apparatus, the melted steel is poured into the mould, and the block L is quickly lowered into position; the screw-clips N N are then to be locked, and the ram Q brought up by its plunger C, and the melted metal thus subjected to great pressure. When the metal has become set, the metal core K is raised, and in rising it will become free from the coating of sand, loam, or refractory material. The metal core K is lifted by admitting water under pressure to the space under the piston R, which piston is set free by unlocking the screw-clip N^1. The core K is raised up through the part M, which remains in position, so that the metal remains still compressed within the mould. In casting steel shells weighing 150 lbs., Whitworth finds the pressure should remain on about eight minutes before the core K is withdrawn. The lifting of the metal core K allows the cavity formed in the hot metal to contract in the latter part of the cooling. The distance between the nuts G and G^1, on the screws D D, is left greater than the depth of the block E, to allow of sufficient movement upwards whilst the pressure is being applied, and to prevent the turn-buckles or stops U U being broken off, and the metal lining H pushed out. The mould F, and also the core shown in the engravings as being used with it, are suitable for casting hexagon shells, but other forms of moulds and apparatus for casting other hollow bodies, such as hoops or cylinders, and others where cores are used, and where it is desired to have the power of withdrawing such cores whilst the casting of steel or iron still remains under pressure in the mould, may be employed in this press.

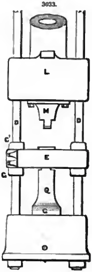
3031.



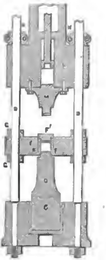
3032.



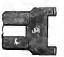
3033.



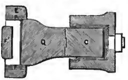
3034.



3035.



3036.



3037.

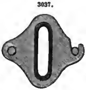


Fig. 3033 shows an elevation of some of the principal parts of a press similar to that already described; Fig. 3034 a vertical section of it; and Figs. 3035 to 3037 show vertical sections of the parts taken at right angles to the section shown at Fig. 3034. The mould here shown is suitable for casting an ingot under great pressure, there being no central core, as in the arrangement just described. The mould F, which is of steel, is suitable for chill-cast ingots of the form shown. F^1 F^2 are the movable top and bottom parts of the mould; the part F is made with inclined sides, and is received into the block or casting E, which is retained in any desired position on the screws D, by the screw-nuts G G^1; the part F^2 of the mould is carried by the ram Q, actuated by the plunger C in the hydraulic cylinder. The part F^1 of the mould is not made so long as the parts F F^2, in order to leave spaces at the end open, through which the melted metal is poured, and the mould on this side is made complete by the two parts F^3 F^3. The parts F^1, F^2, and F^3 are coated with baked sand or loam, and such may be the case when required with the sides of the mould, and where necessary provision is to be made for the getting away of the air and gases, as before described; these coatings of sand prevent the sudden chilling of the metal, and enable smaller ingots to be cast and pressed than would otherwise be possible. In using this arrangement of moulds, the melted metal having been poured in, the block or casting L is lowered, and by this means the upper part or side of the mould is made complete; the screw-clips N are then locked together, and the part F^1 being pressed on by the part M, the hydraulic plunger C is then put into motion, and pressure applied to the fluid metal in the mould. When the article is set and sufficiently cooled, the clips N are unlocked, and the parts connected with the block L raised, and then, by a further motion of the ram Q, the mould and ingot may be lifted out of the block E. Either, or both, of the top and bottom surfaces, F^1 and F^2, may be actuated by hydraulic or other power; when both are so actuated, they should be simultaneously caused to approach each other. In this manner various forms of solid castings may be produced, the moulds being formed accordingly, such, for instance, as cranked or other axles or shafts, the connecting and other rods of steam-engines, and other similar articles; and when the length is considerable, the movable sides of the steel moulds used may be actuated by several hydraulic rams. No rule can be given as to the extent of pressure which may be most advantageously applied in all cases, as the thickness, quantity, and quality of metal acted on vary so largely, whilst the forms of the articles to be cast also differ very largely. Careful observation, however, on the part of the workman will enable him quickly to judge.

It may, however, be desirable to remark, that where the metal in the interior of a casting is found, on cutting or removing the ends or other parts, to have formed itself into irregular crystals, it has not been subjected to sufficient pressure, or the pressure has not been continued for a sufficient length of time. The character of the metal of such a casting, if of steel, may be improved and rendered more uniform throughout by heating it to a moderate red heat, and then subjecting the casting to further pressure, either on end or lengthwise, or both, according as it may be desired to contract or extend the length; this heating and subsequent pressure is also advantageous in removing or breaking off the very hard coating of sand, loam, or other refractory matter employed on the surfaces of the moulds.

By applying the pressure in the manner described, by reference to Figs. 3033 to 3037, to the whole length of the article which is being produced, the pressure may be maintained uniformly on every part until the operation is complete; whereas with plungers acting at the end or on comparatively small parts of the surface of the article, this is not the case, the pressure then ceasing to be uniform when the metal is no longer fluid.

Whitworth remarks that in subjecting fluid steel or iron to very high degrees of pressure in steel moulds, and at the same time cooling it in them, it is of importance that the amount of the pressure applied should always exceed that produced by the shrinking or cooling which is simultaneously going on; or in other words, the pressure applied should be sufficient to overcome the counteracting forces resulting from the rapid cooling of the surfaces of the article, and the slower cooling of the interior metal, so that the atoms are caused to approach each other by the pressure more rapidly than the counteracting forces can separate them.

Caslon and Fagg's Type-founding Machine, Figs. 3038 to 3046.—This invention relates, first, to breaking off the lump or piece of superfluous metal that is cast with and adheres to the body of the type when discharged from the ordinary moulds or machines, and which lump or piece of superfluous metal is usually broken off from the type by hand; and, secondly, to the arrangement of apparatus for rubbing the sides of the cast type and thereby removing the burr or rough edges at the angles of the body of the type.

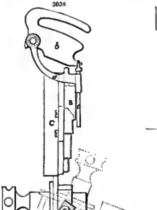
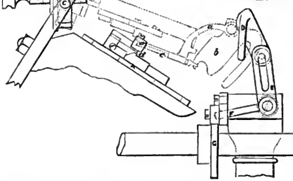
Figs. 3038 to 3042 show two arrangements for effecting the severance of the lump of superfluous metal from the body of the type.

Figs. 3038, 3039, are side and front elevations of this machine; the movable half of the mould being thrown up out of action the better to explain the construction of the parts. A is the fixed die or half of the mould, and B the movable die or half thereof. The movable die is attached to a swinging arm C having its fulcrum at C^1; affixed to the arm C is a bracket *a*, on which is mounted a hook-shaped rocking plate *b*. To the forward end of this plate is connected a finger *c*, which slides in a guide formed for it in the bracket-arm *a*. The object of this finger is to advance at a proper time and move over the gate or entrance of the mould, and assist in severing the lump from the type. When the mould B is brought down into position a curved and cranked bar D will enter the recess formed in the hook-shaped rocking plate *b*. This curved bar is secured by a bolt to the slotted arm of a crank-lever E, the other arm of which enters a slot in a rock-lever F furnished with a roll that lies in contact with a cam G. The rotation of this cam will give a rocking motion through the levers F and E, and the cranked curved bar D to the plate *b*, and thereby cause it to move the finger *c* to and fro in its guide. The bar D is curved to allow of the type-moulds when closed being rocked towards the metal supply cylinder to receive the jet of metal without the position of the plate *b* being affected thereby. When the type-mould is being closed the finger *c* will be drawn to its backward position clear of the surfaces of the moulds, and in that position it will remain until the dies open. As the upper die rises it will carry with it the cast type, suitable provision having been made in that die to secure adhesion, and the finger *c* will be pushed forward over the lump as shown at Fig. 3039. So soon, however, as the upper die B rises to the position shown in Fig. 3038 the head of the type by projecting will come in contact with a shoulder *e* on the stationary die, and the lump or superfluous metal being retained in the die by the finger *c*, the type when hard metal is used in the casting will be broken off and discharged from the die into a suitable receptacle below. The finger *c* will then be withdrawn and the waste end or lump will fall from the die. From this explanation it will be understood that the severance of the waste metal from the body of the type will be effected by an automatic operation.

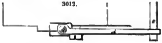
Another mode of effecting this object, and designed chiefly for use when soft type-metal is employed, is shown at Figs. 3040 to 3042. The action of this modification may be best described as a shearing off the superfluous or waste metal. The divided gate of the mould instead of being formed with the dies as usual is made separate and capable of an independent motion. Fig. 3040 is a side view of a mould constructed according to this modification, and Fig. 3041 is a plan view of the lower die, and Fig. 3042 a partial top view, showing the levers for operating the gate.

a, *a**, are the top and bottom dies, and *b*, *b**, the parts that form the gate. They are jointed to the dies, and upon the part *b* bears an adjustable screw *c*, which is carried by a rock-lever *d*. The tail end of this lever is borne up by a lever *e*, which may be operated in any convenient way according to the construction of the machine to which the apparatus is to be fitted. The part *b** is formed with a projection in the under-side of which bears a spring *f*. When a type has been cast by the injection of the metal through the gate as usual the lever *d* will be rocked by the lever *e*, and the gate will thereby be forced down, taking with it the lump or waste piece contained therein; the top die will then rise, lift out the type from the bottom dies, and discharge it as before described, while the waste piece falls out of the gate by its own gravity. The part forming the lower half of the gate will be thrown up into position.

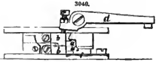
3038.

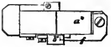
3012.



3040.

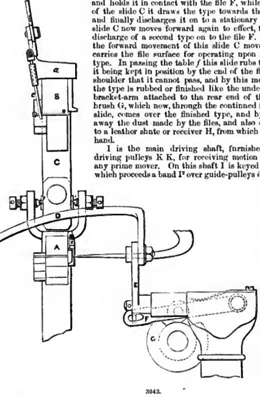


3041.



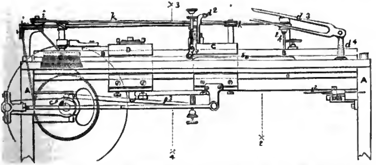
The second part of the invention, which relates to an apparatus for effecting the rubbing or finishing of the body of printing types, which operation has heretofore been effected by hand-labour, is shown in several views, Figs. 3043 to 3046. Fig. 3043 represents the apparatus in longitudinal elevation; Fig. 3044 is a plan; Fig. 3045 is a cross-section taken in the line 1, 2; and Fig. 3046, a cross-section taken in the line 3, 4, of Figs. 3043, 3044. In these views A, A, is the main framing; B, a V-shaped guide for supporting two vertical slides C and D, the uses of which will be presently explained. E is a sliding table, which has a slow endway motion imparted to it, and to which is securely attached a bracket-arm E¹. At F a stationary file is represented secured to the main framing A, and intended to receive the types as they are fed into the machine, and finish on one side. The opposite side is in like manner finished by a file surface carried by the slide D. Mounted on guide-pulleys, on the extremities of the bracket-arm E¹, are vulcanized rubber bands *a*, *a*, which form a kind of endless apron for receiving the type to be operated upon. This type, shown in Fig. 3044, is laid across the bands by an attendant, and by the rotation of the bands the types are carried forward until they are brought under a vulcanized rubber roller *b*, which passes the types forward under a fixed plate *c*, the hinder types pressing forward the forward ones. When the foremost type has come in a line with the file F it is pushed on to that file, the end of the file being made smooth to permit of its sliding off freely. This endway motion of the type is effected by a finger *d*, projecting from a slide d^1, which is actuated through the instrumentality of a roll d^2, carried by the slide C, on which slide is also mounted a pressing pad *e* that now comes down upon the type, and holds it in contact with the file F, while by the back traverse of the slide C it draws the type towards the rear end of the file, and finally discharges it on to a stationary padded table *f*. The slide C now moves forward again to effect, through its roll d^2, the discharge of a second type on to the file F. Simultaneously with the forward movement of this slide C moves the slide D, which carries the file surface for operating upon the upper side of the type. In passing the table *f* this slide rubs the type lying thereon, it being kept in position by the end of the file F, which presents a shoulder that it cannot pass, and by this means the upper side of the type is rubbed or finished like the under side. Mounted in a bracket-arm attached to the rear end of the slide D is a rotary brush G, which now, through the continued forward traverse of the slide, comes over the finished type, and by its rotation brushes away the dust made by the files, and also discharges the type on to a leather shute or receiver H, from which it may be taken up by hand.

3039



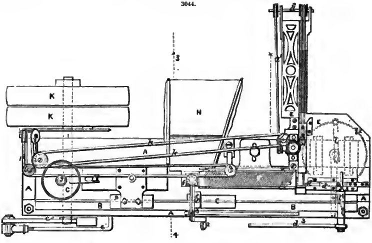
I is the main driving shaft, furnished with fast-and-loose driving pulleys K K, for receiving motion through a strap from any prime mover. On this shaft I is keyed a band-pulley I^1, from which proceeds a band I^2 over guide-pulleys *i i i*, and a double guide-pulley i^1, mounted on a bracket attached to the main framing. This band I^2 passes once around a pulley *g* on the axle of the traversing brush G, then forward to a fixed guide-pulley *h*, back to the pulley i^1, and so to the driving pulley I^1; by this means, therefore, rotary motion is communicated to the brush G. From the double pulley i^1 a band *k* passes to a pulley k^1, keyed to a vertical screw-shaft k^2, which rests in a footstep, and is supported at its upper end by a bracket from the main framing. The screw of this shaft works into a worm-wheel b^1, keyed to the shaft of the vulcanized rubber roller *b*, which, as before stated, takes the type from the bands *a a*, and passes them forward under the guide-plate e to the front end of the file F; the rotation, therefore, of the screw-shaft gives,

3043.

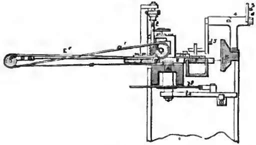


through the worm-wheel b^1, a slow rotary motion to the roller b. The rotation of the bands a is obtained from a band-pulley on the end of the worm-wheel b^1 by means of a band a^1, which passes over and drives a pulley keyed to the short shaft a^2, on the opposite end of which is keyed the outer pulley for receiving the bands a. The inner pulley, which keeps these bands at tension, is shown at a^3, Figs. 3044, 3045. The traverse motion of the slides C and D is obtained from the main driving shaft I, through a connecting rod C^1, jointed at its forward end to the slide C, and at its rear end to a poised crank-arm C^2 on the end of the shaft I. A metal strap connects the slides C and D together. For giving the motion to the finger d which pushes the type on to the file F, the roll d^3, as it moves forward, is caused to enter the forked arm d^2 of a crank-lever carried by a bracket-arm d^4. The arm d^5 of this lever carries a crank-pin, which works in a fork projecting upwards from the slide d^1. As, therefore, the roll d^3 traverses within the forked arm, that arm will be caused to rock, and thereby traverse the slide d^1 in its guides, and thrust forward the finger d at the proper time for discharging the type on to the file surface F. In order to bring down and retain the pad e in contact with the type on the file surface while travelling back with the slide C, the pad is mounted on a sliding stem e^1, which works in a guide fixed to the slide C. Bearing on the upper end of this stem is an adjusting screw carried by a rock-lever e^2, which has its fulcrum on the guide-bracket; jointed to the opposite end of this rock-lever is a sliding bar e^3, working in suitable guides on the slide C, and jointed to the lower end of this sliding bar is a tumbling piece e^4, which carries at its lower end a small friction-roll. This roll works over a raised bar e^5, on the main framing, and during the forward progress of the slide C the tumbling piece is drawn loosely over the bar. When, however, the back traverse commences, the tumbling piece will be forced into an upright position, thereby driving up the sliding bar e^3, the effect of which will be to press down the adjusting screw of the rock-lever e^2 on to the stem e^1 of the pad e, and thus depress the pad e, and cause it to press upon the type last pushed forward on to the file surface F. The continued backward motion of the slide will enable the pad e to draw the type over the file F, as before mentioned, and discharge it on to the table f. Having effected this operation, the pad will be caused to rise by means of a coiled spring surrounding its stem, the

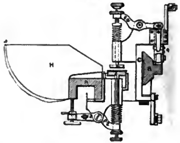
3044.



3045.



3046.



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tumbler meanwhile having arrived at the end of the raised bar e^5, and thereby removed the upward thrust from the rock-lever, and allowed the spring to act. A similar motion to that described for the pad *e* is imparted to the table *f*, for the purpose of pressing the type up against the file surface carried by the slide D, which surface, as before mentioned, operates upon and finishes the upper side of the type. This table *f* is carried by a vertical stem f^1, and is held down by a coiled spring. An adjustable screw, carried by a rock-lever f^2, having its fulcrum on the stem-guide which is attached to the main framing, serves to press up the table when required. This rock-lever f^2 is itself operated by a rock-lever f^3, Fig. 3043, which enters a slot in the lever f^2, and carries at its other end a roll that bears a cam f^4 on the driving shaft. The fulcrum of the lever f^3 is carried by a bracket pendent from the framing A, and as the lever is rocked by the *cam* it will raise the table *f*, and keep the type in contact with the rubbing surface of the passing slide D. When, however, that slide has acted, the rock-lever will allow the table to fall into the position for receiving another type.

In order that the successive types may take different lines of traverse over the file surface F, a continuous lateral motion is given to the table E. This is effected by mounting it on guides, and connecting it by a link *l*, with a vertical crank-shaft l^1, carried by the main framing. At the lower end of this shaft is keyed a ratchet-wheel l^2, into the teeth of which takes a click which is carried by a loose arm l^3. As the slide C moves forward, it strikes against this arm, and causes the click to drive round the ratchet-wheel a certain distance; a spring l^4, when the slide retires, throws back the arm to its quiescent position. This action being repeated, the crank-shaft will be caused slowly to rotate, and thus shift each successive type into a different position relatively to the file surface F, thereby causing each portion of the surface to act in turn upon the successive types.

See ALLOYS. ASSAYING. BLAST FURNACE. FURNACE. GEARING. MOULDING. PIN-MAKING MACHINE. REAGENTS AND FLUXES. See also articles on the various Metals.

FOUNDRY. FR., *Fonderie*; GER., *Giesserei*; ITAL., *Fonderia*; SPAN., *Taller de fundicion.*

A *foundry* is a building arranged and fitted for casting metals. See FOUNDING AND CASTING.

FRICK'S METAL. FR., *Métal de Frick*; GER., *Frick 'sches Metall.*

See ALLOYS.

FRICTION. FR., *Frottement*; GER., *Reibung*; ITAL., *Attrito*; SPAN., *Friccion; rozamiento.*

We usually distinguish two kinds of friction. One, called *friction of sliding*, is produced when bodies slide one upon the other, whence it results that the primitive points of contact are found ceaselessly at distances respectively different from new points of contact, which is expressed in saying that they have experienced displacements, relatively unequal, and in opposite directions. The second kind of *friction*, improperly called *rolling friction*, takes place when bodies roll one upon the other, when the distances of the new points of contact from the old are the same upon both bodies, and when the relative displacements are equal. As the word friction implies, generally, the idea of sliding, and not that of rolling, it will be proper to admit only one kind of friction, that of sliding, and to designate the other by the name of *resistance to rolling.*

Review of Ancient Experiments.—The first experiments known upon the friction of sliding are due to Amontons, and are inserted in the Memoirs of the Ancient Academy of Sciences, 1699. This philosopher knew that friction was independent of the extent of surfaces, but he estimates its value at a third of the pressure for wood, iron, brass, lead, &c., coated with lard, which is far too much.

Coulomb in 1781 presented to the French Academy of Sciences, experiments made at Rochefort, and much more complete than those of Amontons. The apparatus he used consisted of a bench, formed of two horizontal timbers 6 ft. long, upon which a sledge loaded with weights slid by the action of a weight suspended to a cord, which, passing over a fixed pulley, was attached horizontally to the sled.

By means of this disposition, Coulomb at once determined the effort necessary to produce motion after the bodies had remained some time in contact. This is what he called the *resistance or friction of departure.* He saw that this friction was proportional to the pressure, and he expected to find it composed of one part proportioned to the extent of the surface of contact, which he termed adhesion—and of another part independent of this surface. He then sought the value of friction during motion, and for this effect he observed, with a stop-watch of half seconds, the time employed by the sled in running successively the first 3 ft. and the next 3 ft. of its course.

But as in these durations, sometimes equal to 1″ or 2″, he might be mistaken by a half second at the end, and also at the commencement of the experiment, there resulted very great uncertainties which did not admit of establishing his conclusions in a positive manner, and we may say he rather conjectured than observed the laws which he inferred from his experiments. Still he admitted that, generally, friction during motion is;—

1st. Proportional to the pressure.

2nd. That it is independent of the extent of the surfaces of contact.

3rd. That it is independent of the velocity of motion, with some restrictions, which subsequent experiments did not confirm.

Coulomb also first established the fact, that for compressible bodies, the friction at starting, or after a contact of some duration, was greater than it was after the first displacement.

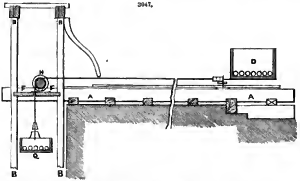
Experiments at Metz.—The uncertain observations, and the restrictions adduced by Coulomb, and above all the more general use of metals in the construction of machines, called for a new series of experiments, which Merin made at Metz, in 1831, '32, '33, and '34, by means of new processes.

Summary Description of the Apparatus used.—In the smelting yards of this ancient foundry, upon a flag-stone foundation, and at the side of a trench, Fig. 3047, was established a horizontal bed, composed of two parallel oak beams A A, 0·98 ft. square, and 26·24 ft. long, connected and supported by sleepers 3·28 ft. apart. These beams, which jutted about 4·26 ft. beyond the edge of the trench, were connected with four uprights B B, between which was placed a platform F F, which bore the pulley for passing the cord, to which was suspended the motive weight, placed in a box K.

This cord was fixed horizontally to a sled D, charged with weights, under which was placed the body to be experimented upon.

The cord, instead of being attached directly to the sled, was fastened to the front plate of a dynamometer with a style, whose flexure measured the tension of the cord, both at its starting and during its motion.

3047.



The axis of the pulley had a copper-plate H, perfectly smooth and covered with a sheet of paper. Opposite this plate, clockwork communicated uniform motion to a style, formed of a brush filled with India ink, whose point described a circle 0·459 ft. in diameter. The parallelism of the plane of the circle, and that of the plate, was also perfectly established by precise methods, and the contact of the brush was produced or interrupted at will.

Upon the box K may be placed two others for holding weights, which, after producing the motion, may at a certain height be stopped by cleats, so that the motion continues only in virtue of the load and weight of the box Q. By this means, we may at will obtain, with the box Q alone, an accelerated motion, and with the three boxes, a motion at first accelerated, then uniform or retarded, according as the weight of the box is sufficient to overcome the friction or is inferior to this resistance.

Examination of the Graphic Results of Experiments.—From the synchronism of the two motions, the one of the style being uniform and with a known velocity, and the other unknown, corresponding in a constant ratio with the spaces described by the sled, there must result a curve whose abstract will give us the law of the motion of the sled. We may then, by this abstract, form a table of spaces described, and of the corresponding times, and construct a curve whose abscissæ are the spaces, and whose ordinates are the times. The curves thus constructed are perfectly continuous, and we see, as has been indicated, page 5, that they are parabolas, that is to say, their abscissæ are proportional to the square of their ordinates.

From the fact of this curve being a parabola, we are justified in the inference that the motion is uniformly accelerated. Now, the motive weight being constant, the motive force producing the acceleration of motion is the excess of this weight above the friction, and since this excess is constant, it follows, necessarily, that the friction is constant and independent of the velocity.

Experiments repeated with all the bodies used in the construction of machines, with or without unguents, having always led to the same consequences, we are authorized in regarding this law as general, at least within the limits of the velocity of observation; that is to say, of about 11·5 ft., and in the assumption that the restrictions which Coulomb anticipated have no existence in reality. See p. 1315.

Formulæ employed in Calculating the Results of Experiments.—The apparatus which we have just described affords a simple example of a machine in which the motion is variable, and enables us to apply the general principles which we have previously pointed out. We take advantage of it to show the method of procedure in similar cases.

We call P the weight of the descending box, including its load and that portion of the cord which hangs always under the pulley, neglecting, however, the quantity by which it is increased in its descent, which seldom exceeds 2 lbs.; T the tension of the horizontal strip; $q = 13{\cdot}79$ lbs., the weight of the pulley.

V_1 the angular velocity of the pulley at the instant considered.

v_1 the quantity by which the velocity varies in an element of time t.

$I = {\cdot}04551$ the moment of inertia of the pulley and of the pieces turning with it.

$f = 0{\cdot}164$ a ratio determined by special experiments, of the friction to the pressure, for the iron axle of the pulley and the ash-wood cushions greased; $R = 0{\cdot}032\,T$ the rigidity of the twisted cord, determined also by especial experiments.

N the pressure of the axle of the pulley upon the journals.

r the radius of the pulley.

r' the radius of its journals.

If we refer to the principles upon the motion of variable rotation, pp. 43, 103, 303, 1349, we shall see that at each instant of the motion of the pulley, the sum of the moments of the exterior forces must be equal to the sum of the moments of the forces of inertia.

Now, the sum of the moments of the exterior forces is $P\,r - T\,r - R\,r - f\,N\,.\,r'$. The sum of the moments of the forces of inertia answering to a velocity v_1 of angular velocity is easily found; for, one of these forces, relative to a molecule of the mass m, situated at a distance r_1 being $m\,.\,\frac{v_1\,r_1}{t}$, its moment in respect to the axis is $m\,r_1^2\,\frac{v_1}{t}$, and the sum of the similar moments is $I\,\frac{v_1}{t}$, for all parts turning around the axis.

The moment of inertia of the weight P is $\frac{P}{g}\,\frac{v_1\,r}{t}\,r$, and must be added to the preceding; we have then, at each instant of variable motion of the pulley, the relation

$$P\,r - T\,r - R\,r - f\,N\,r' = I\,\frac{v_1}{t} + \frac{P}{g}\,\frac{v_1\,r}{t}\,r.$$

The pressure N upon the axle of the pulley being the resultant of two perpendicular forces, the one horizontal equal to the tension T, the other vertical and equal to the weight P of the box, increased by the weight of the pulley, and diminished by the force of inertia $\frac{P}{g}\,\frac{v_1\,r}{t}$, which is developed in the acceleration of the vertical motion of the weight P, and is opposed to its acceleration; we have then

$$N = \sqrt{\left(P + q - \frac{P}{g}\,\frac{v_1\,r}{t}\right)^2 + T^2}.$$

Now, according to an algebraic theorem of Poncelet, the value of a radical of the form $\sqrt{a^2 + b^2}$, in which we know beforehand that $a > b$ is given to nearly $\frac{1}{25}$ by the formula $0{\cdot}96\,a + 0{\cdot}4\,b$. In applying it to the case in hand, where we have always $P + q - \frac{P}{g}\,\frac{v_1\,r}{t} > T$, since the weight P exceeds the resistance T and the friction of the sled, we have to $\frac{1}{25}$ nearly

$$N = 0{\cdot}96\left\{P + q - \frac{P}{g}\,\frac{v_1\,r}{t}\right\} + 0{\cdot}4\,T.$$

The relation of the equality of moments becomes then, in making $R = 0{\cdot}032\,T$,

$$P\,r - T\,r - 0{\cdot}032\,T\,r - 0{\cdot}96\,f\,r'\left\{P + q - \frac{P}{g}\,\frac{v_1\,r}{t}\right\} - 0{\cdot}4\,f\,r'\,T = \frac{I\,v_1\,r}{r\,t} + \frac{P}{g}\cdot\frac{v_1\,r}{t}\,r,$$

and in deriving from this equation of the first degree the value of T, the tension of the horizontal strip of the cord, we find

$$T\left\{1 + 0{\cdot}032 + 0{\cdot}4\,\frac{f\,r'}{r}\right\} = P\left\{1 - 0{\cdot}96\,\frac{f\,r'}{r}\right\} - 0{\cdot}96\,f\,q\,\frac{r'}{r} - \frac{P}{g}\,\frac{v_1\,r}{t}\left\{1 - 0{\cdot}96\,\frac{f\,r'}{r}\right\} - \frac{I}{r^2}\,\frac{v_1\,r}{t}.$$

In substituting for the known quantities their values, which are

$$f = 0{\cdot}164,\quad r' = 0{\cdot}030512 \text{ ft.},\quad r = 0{\cdot}36417 \text{ ft.},\quad I = {\cdot}04551,$$

whence $\frac{I}{r^2} = 0{\cdot}34317$, we have for the practical formula which gives the tension T, when we know the weight P of the box, $T = 0{\cdot}95\left\{P - \left({\cdot}34685 + \frac{P}{g}\right)\frac{v_1\,r}{t}\right\} - 0{\cdot}1753$ lb.

When experiment has demonstrated that the acceleration $\frac{v_1\,r}{t}$ is constant, and the abstract of the curves, in giving their equation $T^2 = 2\,C\,E$, shall have furnished for the acceleration the value $\frac{v_1\,r}{t} = \frac{1}{C}$, in calling $2\,C$ the parameter of the parabola, we shall have all the elements required to calculate the value of the tension of the cord in the experiment. It will be

$$T = 0{\cdot}95\left\{P - \left({\cdot}34685 + \frac{P}{g}\right)\frac{1}{C}\right\} - {\cdot}1753 \text{ lb.}$$

When the motion is uniform the acceleration $\frac{v_1\,r}{t} = \frac{1}{C}$ is zero, and the above formula is reduced to $T = 0{\cdot}95\,P - 0{\cdot}1753$ lb., or simply $T = 0{\cdot}95\,P$, on account of the small value of the second term ·1753 lb.

In extracting directly from the curves of tension of the dynamometer, the values of T relative to more than forty experiments, in which the loads have varied from 26 to 209½ lbs., we have found that the ratio of the tension to the load, thus furnishing a direct measurement, was at 0·96, which shows that all the data introduced in the above formula leads to a result which accords with this measure, within very satisfactory limits of correctness.

Relations between the Tension of the Cord and the Friction of the Sled.—Knowing the tension of the cord T, by means of the dynamometer, or having calculated it by the preceding formula, it is quite easy to deduce the value sought, of the friction of the sled, in applying directly the principle of action equal and opposite to reaction. In fact, the tension T, and the friction sought F, are two external forces with opposite directions, whose difference T − F produces the motion of acceleration of the sled. On the other hand, the resistance which the inertia of the weight Q of the sled opposes to this *acceleration* is $\frac{Q\,v_1\,r}{g\,t}$.

We have then for the equality of action and reaction, $T - F = \frac{Q}{g}\,\frac{v_1\,r}{t} = \frac{Q}{g} \cdot \frac{1}{C}$, whence

$$F = T - \frac{Q}{g} \cdot \frac{1}{C}.$$

When, by direct observation, or by the formula of the preceding number, we shall have determined the tension of the cord, we must for the value of the friction subtract from it the quantity $\frac{Q}{g}\,\frac{1}{C}$, easily calculated when we know by the abstract the parameter 2 C of the curve of motion.

Such is the method which was adopted for the calculation of all the experiments where the motion was accelerated; as for those where the motion is uniform, we have simply F = T.

We see that the law of the motion being once known by the abstract of the curves, and being that of a uniformly accelerated motion, we may, after having proven the constancy and the generality of this law, pass to the use of the dynamometer, and rest content with the indications of the chronometric apparatus.

Results of Experiments.—The friction of oak, sliding upon oak without unguent, with the fibres parallel to the direction of the motion.

In this experiment we have Q = 295·22 lbs.; P = 203·38 lbs.

The trace of the curve gives for the parameter 2 C = 0·6339 ft., whence $\frac{1}{C} = 3{\cdot}154$, and consequently the tension $T = 0{\cdot}95\left\{P - \left(0{\cdot}34685 + \frac{P}{g}\right)\frac{1}{C}\right\} - {\cdot}1753 = 173{\cdot}05$ lbs.

The other formula gives for the value of friction $F = T - \frac{Q}{g} \cdot \frac{1}{C} = 144{\cdot}1$ lbs.

The ratio of the friction to the pressure is here then $\frac{F}{Q} = \frac{144{\cdot}1}{295{\cdot}2} = 0{\cdot}488$.

EXPERIMENTS UPON THE FRICTION OF OAK UPON OAK, WITHOUT UNGUENTS; THE FIBRES OF THE WOOD BEING PARALLEL TO THE DIRECTION OF MOTION.

Extent of Surface of Contact.	Pressure, Q.	Motive Weight during Motion, P.	Tension of the Cord, T.	Parameter.	Value of the Acceleration, $\frac{1}{C}$.	Friction, F.	Ratio of Friction to Pressure, $\frac{F}{Q}$.	Velocity of Motion,	
								Uniform.	Acceleration at 8·84 ft. of its Course.
sq. ft.	lbs.	lbs.	lbs.	feet.		lbs.		feet.	feet.
2·798	295·22	148·58	141·15	..	..	141·15	0·477	2·264	..
	295·22	203·38	173·02	0·634	3·123	144·1	0·488	..	7·77
	333·52	171·03	162·48	..	..	162·48	0·487	..	..
	970·63	504·32	479·10	..	..	479·44	0·491	1·345	..
	970·63	610·01	536·64	0·850	2·352	466·41	0·480	..	6·726
	1499·13	930·23	819·18	0·862	2·320	709·33	0·472	..	6·693
	2291·56	1273·69	1164·91	1·688	1·184	1080·60	0·471	..	6·299
	2291·56	1114·91	1059·16	..	..	1059·16	0·462	3·511	..
1·062	102·09	64·95	54·17	1·914	1·044	50·86	0·498	..	4·495
	108·53	56·59	53·77	..	..	53·77	0·496	4·20	..
	120·55	62·90	59·75	..	..	59·75	0·495	4·92	..
	120·55	98·39	76·44	0·384	5·208	56·95	0·472	..	10·072
	226·81	186·83	152·57	0·472	4·237	110·38	0·486	..	8·924
	227·63	132·64	117·77	1·054	1·897	104·36	0·458	..	6·102
	332·76	162·72	154·58	..	..	154·58	0·464	4·101	..
	440·03	211·37	200·80	..	..	200·84	0·456	2·001	..
	440·24	210·45	199·93	..	..	199·93	0·454	2·789	..
0·33	215·67	108·62	103·19	..	..	103·19	0·478	3·478	..
	321·47	175·49	164·74	0·933	2·145	133·34	0·414	..	6·918
	604·06	468·80	389·44	0·506	3·952	293·51	0·484	..	8·858

When the motion is uniform, as in the sixteenth experiment of the above Table, we have simply for

$$Q = 440{\cdot}37 \text{ lbs.},\quad P = 211{\cdot}37 \text{ lbs.},$$

$$F = 0{\cdot}95\,P = 200{\cdot}84,\quad f = \frac{F}{Q} = \frac{200{\cdot}84}{440{\cdot}37} = 0{\cdot}456.$$

EXPERIMENTS UPON THE FRICTION OF ELM UPON OAK, WITHOUT UNGUENTS; THE FIBRES OF THE WOOD BEING PARALLEL TO DIRECTION OF MOTION.

Surface of Contact.	Pressure, Q.	Motive Weight during Motion, P.	Tension of the Cord during Motion, T.	Parameter, 2 C.	Accelera- tion, $\frac{1}{C}$.	Friction.	Ratio of Friction to Pressure, *f*.	Velocity at 9·84 ft. of its Course.
sq. ft.	lbs.	lbs.	lbs.	feet.		lbs.		feet.
1·338	260·05	161·31	139·19	0·732	2·731	117·18	0·45	7·55
	260·05	187·42	153·06	0·469	4·261	118·88	0·45	9·45
	921·38	506·69	450·40	0·984	2·031	392·27	0·43	3·60
	921·38	480·24	440·46	1·859	1·075	408·73	0·44	4·62
	921·38	454·13	416·77	1·902	1·051	386·62	0·42	4·48
	921·38	664·42	525·72	0·377	5·291	374·53	0·41	12·46
	1980·10	1113·83	976·94	0·802	2·494	821·76	0·42	7·41
	1980·10	1007·77	927·09	1·993	1·003	865·54	0·44	4·04
	1980·10	1113·83	911·42	1·206	1·657	787·42	0·40	5·68
	1980·10	1298·70	1104·86	0·600	3·330	899·99	0·45	8·10
·063	244·81	135·42	122·36	1·414	1·414	108·93	0·45	5·25
	389·58	311·19	240·06	0·347	5·756	171·43	0·44	10·50
	917·79	479·76	439·82	1·734	1·153	408·60	0·44	4·76
						Mean ..	0·434	

EXPERIMENTS UPON THE FRICTION OF SOFT OOLITIC LIMESTONE OF JAUMONT, NEAR METZ, UPON STONE OF THE SAME KIND, WITHOUT UNGUENT.

Surface of Contact.	Pressure, Q.	Motive Weight during Motion, P.	Tension of the Cord during Motion, T.	Parameter, 2 C.	Accelera- tion, $\frac{1}{C}$.	Friction, F.	Ratio of Friction to Pressure, $\frac{F}{Q}$.	Velocity of 9·84 ft. of its Path.
sq. ft.	lbs.	lbs.	lbs.	feet.		lbs.		feet.
0·861	314·04	254·18	222·40	0·829	2·412	198·89	0·633	6·890
	314·04	254·18	218·36	0·682	2·929	187·60	0·597	7·579
	1264·18	999·63	853·54	0·621	3·216	727·50	0·575	7·940
	1374·94	1034·92	859·41	0·499	4·001	700·86	0·549	8·858
	1274·94	1034·92	859·41	0·499	4·001	700·86	0·549	8·858
						Mean ..	0·580	
0·499	309·56	293·88	245·40	0·536	3·725	209·56	0·677	8·498
	331·62	293·88	244·65	0·524	3·815	207·97	0·627	8·662
	1257·50	1034·92	925·13	1·066	1·874	851·95	0·677	6·070
	1257·50	1140·78	943·99	0·488	4·101	783·89	0·623	8·990
	1257·50	1140·78	924·32	0·426	4·687	741·28	0·589	9·013
						Mean ..	0·639	
Rounded edges.	298·40	240·95	218·30	1·426	1·402	205·31	0·688	5·249
	298·40	240·95	211·02	0·841	2·377	189·01	0·633	6·824
	298·40	293·88	239·18	0·451	4·433	198·10	0·664	9·350
	597·93	465·91	421·45	1·341	1·491	393·79	0·659	5·413
	597·93	465·91	431·15	2·499	0·800	416·28	0·696	3·970
	597·93	571·77	485·40	0·597	3·347	423·25	0·709	8·104
						Mean ..	0·675	
					General Mean ..		0·631	

When the soft limestone slides upon soft limestone, and especially when the moving body rests upon surfaces of small area, the latter are destroyed rapidly during the experiment. This circumstance, and the presence of the dust powder resulting from it, have not changed the laws observed.

Though leather is a soft and very compressible substance, its friction is proportional to the pressure, and independent of the velocity, throughout the whole range of the experiments in the next Table.

EXPERIMENTS UPON THE FRICTION OF STRONG LEATHER, TANNED, AND PLACED FLATWISE UPON CAST IRON.

Area of Surfaces in Contact.	Nature of the Unguent.	Pressure.	Motive Weight during the Motion.	Tension of the Cord.	Parameter.	Value of the Acceleration, $\frac{1}{C}$.	Friction.	Ratio of Friction to Pressure.	Velocity at 9·84 ft. of its Course.
sq. ft.		lbs.	lbs.	lbs.	feet.		lbs.		feet.
0·4155	Nothing.	471·02	320·35	291·83	1·548	1·292	272·75	0·579	5·02
		1106·42	637·94	606·04	..	..	606·04	0·547	..
							Mean ..	0·563	
0·4155	Water.	291·01	188·02	154·78	0·497	4·024	118·63	0·408	8·86
		291·01	161·55	133·85	0·524	3·816	96·44	0·342	8·66
		291·01	135·08	118·83	0·926	2·159	99·49	0·342	6·56
		1115·03	977·58	689·54	0·244	8·196	407·11	0·365	12·70
							Mean ..	0·364	
0·4155	Tallow.	1114·10	214·48	193·80	2·042	0·979	163·21	0·146	4·53
		1114·10	214·48	198·54	2·584	0·776	172·38	0·155	3·87
		1114·10	320·36	279·52	0·795	2·516	192·43	0·172	7·09
		1114·10	426·10	350·41	0·475	4·210	182·99	0·164	9·06
							Mean ..	0·159	
0·4155	Oil.	298·49	39·26	37·30	..	..	37·29	0·124	..
		299·17	92·19	76·29	0·548	3·649	42·52	0·142	8·46
		1114·10	148·32	140·91	..	..	140·91	0·126	..
		1114·10	214·48	196·22	1·804	1·108	157·93	0·141	4·59
							Mean ..	0·133	
	Oily surface.	1114·10	320·35	294·48	2·011	0·944	260·07	0·233	4·66
		478·92	135·08	123·77	1·950	1·025	108·66	0·227	4·66
							Mean ..	2·30	

EXPERIMENTS UPON THE FRICTION OF BRASS UPON OAK, WITHOUT UNGUENT; FIBRES OF WOOD PARALLEL TO THE DIRECTION OF MOTION.

Surface of Contact.	Pressure.	Motive Weight during Motion.	Tension of the Cord.	Parameter.	Acceleration, $\frac{1}{C}$.	Friction.	Ratio of Friction to Pressure.	Velocity at 8·84 ft. of Course.
sq. ft.	lbs.	lbs.	lbs.	feet.		lbs.		feet.
·433	257·13	161·46	153·36	..	..	153·39	0·60	..
	257·13	161·61	153·61	..	..	153·54	0·60	..
	1539·90	981·99	932·69	..	..	932·89	0·60	..
	1539·90	1114·32	1068·80	1·548	1·291	1007·79	0·65	..
	1539·90	1273·11	1101·97	0·707	2·828	967·05	0·62	7·48
	1989·83	1378·97	1290·72	4·346	0·460	1262·61	0·63	3·05
0·141	248·31	161·72	153·60	..	..	153·61	0·61	..
	248·49	188·36	169·56	1·283	1·558	157·58	0·63	5·21
	763·97	532·07	487·11	1·956	1·022	462·90	0·60	4·92
	1531·26	981·89	932·69	..	..	932·89	0·61	..
	1531·26	1273·11	1103·69	0·719	2·780	971·73	0·63	7·51
						Mean ..	0·616	

For the experiments where we hove not indicated tho value of the parameter of the law of motion, and that of the acceleration, the motion was slow and somewhat uncertain.

The results contained in this Table confirm the three laws before enumerated, but we remark that the mean value of the friction, which is here 616, is more considerable than in the case of oak rubbing against oak, or than that of elm upon oak, for which the results are consigned to the Tables of pages 1572 and 1573.

We shall see, by the following Table, that the coefficient diminishes considerably when the friction occurs between two metallic surfaces.

Experiments upon the Friction of Cast Iron upon Cast Iron.

Surfaces of Contact.	Un-guent.	Pressure, Q.	Motive Weight during the Motion.	Tension of the Cord during the Motion.	Para-meter, 2 C.	Accele-ration, $\frac{1}{C}$.	Friction	Ratio of Friction to Pressure.	Velocity at 9·84 ft. of Path.	
sq. ft.		lbs.	lbs.	lbs.			lbs.		feet.	
0·3874	Noth.	496·10	108·62	95·78	0·993	2·012	64·49	0·130	6·37	Slew.
		496·10	135·09	113·38	0·585	3·417	60·79	0·122	8·20	
		1091·14	320·37	283·32	0·938	2·130	211·15	0·193	6·50	
		1091·14	426·08	336·38	0·378	5·291	157·18	0·144	10·17	
		1104·80	174·79	166·05	..	..	166·05	0·150	..	
		4412·70	796·73	745·58	4·267	0·468	681·74	0·154	3·25	
		4412·70	929·06	865·85	3·316	0·604	783·54	0·177	3·48	
		4412·70	1054·77	949·52	1·158	1·726	712·94	0·161	5·81	
							Mean ..	0·154		
0·3874	Water.	1104·37	399·74	361·17	1·402	1·426	312·32	0·282	8·90	Uniform.
		1104·37	505·61	432·96	0·646	3·095	324·60	0·293	9·25	
		2202·70	770·26	731·36	..	..	731·36	0·332	..	
		2202·70	876·13	806·43	2·036	0·982	739·30	0·336	4·53	
							Mean ..	0·311		
0·3874	Soap.	1091·14	201·25	191·15	..	..	191·15	0·175	..	Slow.
		1091·14	320·37	287·77	1·251	1·598	231·00	9·211	5·68	
		1091·14	373·30	321·78	0·695	2·878	224·47	0·205	7·09	
							Mean ..	0·197		
0·3874	Tallow.	496·10	52·49	49·87	..	..	49·87	0·100	..	Slow.
		496·10	78·96	65·48	1·950	1·024	50·40	0·101	4·56	
		1103·43	108·64	103·17	..	..	103·17	0·093	..	Slow.
		1103·43	201·25	179·20	1·060	1·885	114·64	0·104	6·17	
		1103·43	240·95	212·87	0·939	2·130	117·81	0·106	6·47	
		2214·98	293·88	271·14	2·286	0·875	211·30	0·095	4·20	
		2214·98	293·88	274·54	4·023	0·497	243·34	0·109	3·08	
		2214·98	426·10	379·70	0·999	2·000	243·33	0·109	6·30	
		6185·82	624·70	593·47	..	..	593·47	0·096	..	Very slow.
		1108·14	108·62	103·17	..	..	103·17	0·093	..	Slow.
							Mean ..	0·101		
0·3874	Lard.	1103·43	129·48	118·70	2·011	0·994	84·02	0·076	4·53	
			129·48	118·13	1·767	1·131	79·44	0·071	4·72	
			133·89	121·19	1·395	1·432	72·16	0·065	5·61	
			133·89	120·99	1·414	1·414	72·54	0·066	5·58	
			138·31	126·29	1·767	1·131	85·82	0·077	4·59	
			138·31	124·41	1·295	1·544	71·55	0·065	5·51	
			138·35	123·55	1·341	1·491	72·71	0·066	5·44	
			138·35	124·41	1·295	1·544	71·55	0·065	5·51	
			193·44	168·15	0·783	2·553	80·65	0·073	7·12	
			193·44	167·07	0·731	2·734	72·94	0·066	7·28	
			193·44	168·92	0·823	2·430	85·68	0·078	6·82	
							Mean ..	0·070		

This Table, besides verifying the laws of the proportionality of the friction to the pressure, and its independence of the velocity, shows that water rather increases than diminishes the friction of cast iron. We see also that tallow, somewhat hard, does not reduce the friction so much as lard.

Consequences of the Experiments.—The experiments made by Morin upon the friction proper of plane surfaces upon each other comprise 179 series, answering to different cases, according to the nature or condition of the surfaces in contact; and they all, without exception, lead to the following results;—

The friction during the motion is—

1st. Proportional to the pressure.

2nd. Independent of the area of the surfaces of contact.

3rd. Independent of the velocity of motion.

Experiments upon the Friction at Starting, or when the Surfaces have been some time in contact.—The same apparatus has served for the experiments upon friction at the start, or after a prolonged contact, whose aim was to establish in what cases there is a notable difference between it and that produced during motion. This difference, which, according to the case, arises from very different causes, may in general be attributed to the reciprocal compression of the bodies upon each other, and to a kind of gearing of their elements. The time or duration of the compression probably exerts an influence upon the intensity of the resistance opposed by their surfaces to sliding. But generally this resistance reaches its maximum at the end of a very short period.

Experiments upon the Friction of Oak upon Oak, without Unguents, when the Surfaces have been some time in contact; the Fibres of the Sliding Pieces being perpendicular to those of the Sleeper.

Extent of the Surface of Contact.	Pressure, Q.	Motive Effort or Friction, F.	Ratio of the Friction to the Pressure, *f*.
sq. ft.	lbs.	lbs.	
0·947	120·55	67·15	0·55
	282·49	150·23	0·53
	495·01	252·34	0·51
	1995·23	1171·10	0·58
	2526·65	1287·16	0·51
0·043	389·35	203·80	0·52
	402·98	212·44	0·53
	1461·08	851·77	0·58
		Mean ..	0·54

The friction seems to be proportional to the pressure, which varied from 120 lbs. to 2526 lbs., and independent of the surfaces of contact, which varied in the ratio of 1 to 22, the smallest being ·043 sq. ft., and the greatest 0·947 sq. ft.; this last value exceeds those usually employed for sliding surfaces in mechanical constructions.

The ratio of the friction to the pressure is here raised to 0·54, while it was only 0·48 during the motion, as was the result of the Table, page 1572. The friction at the start is raised then about an eighth above that which we first considered. A similar increase occurs in all similar cases.

Experiments upon the Friction of Oak upon Oak, without Unguents, when the Surfaces have been some time in contact. The Sliding Pieces have their Fibres vertical, those of the Fixed Pieces are horizontal and Parallel to the Direction of Motion.

Extent of the Surface of Contact.	Pressure, Q.	Motive Effort or Friction, F.	Ratio of Friction to Pressure, *f*.	Time of Contact.
sq. ft.	lbs.	lbs.		
·6845	432·12	184·88	0·427	5 to 6″
	432·12	184·88	0·427	10′
	432·12	157·43	0·364	1′
	696·77	354·59	0·509	6′
	696·77	304·31	0·436	30″
	696·77	342·03	0·498	8 to 10′
	882·01	405·32	0·459	8 to 10′
	1106·99	555·73	0·502	10′
	1106·99	430·03	0·388	5 to 6″
	2205·30	810·24	0·367	15′
	2205·30	882·60	0·400	10′
		Mean ..	0·434	

This Table shows that for wood the friction at the start presents for equal surfaces and pressures great differences from one experiment to another, and that the resistance attains its maximum in a short time of contact, which seems not to exceed some seconds. We, in fact, see that the figures answering to five and six seconds are not inferior to those relating to a contact of fifteen minutes, the longest of any recorded in the Table.

The mean value of the ratio *f* of friction to the pressure is 0·434, but it would be well in application to reckon it at 0·48 or even 0·50.

We still see by these experiments, in the following Table, that the friction at starting, as well as the friction in motion, is independent of the extent of the surface of contact, and is proportional to the pressures.

These figures, moreover, differ so little from each other, that we may place all confidence in the general mean 0·74, and employ it in all similar cases.

EXPERIMENTS UPON THE FRICTION OF OOLITIC LIMESTONE UPON OOLITIC LIMESTONE, WHEN THE SURFACES HAVE BEEN FOR SOME TIME IN CONTACT.

Surface of Contact.	Pressure, Q.	Motive Effort or Friction, F.	Ratio of Friction to the Pressure, f.	Time of Contact.
sq. ft.	lbs.	lbs.		
0·8611	314·01	228·88	0·728	15′
	330·85	239·25	0·723	15′
	1162·72	949·64	0·752	15′
	1274·93	932·87	0·731	5 to 6″
	1274·93	958·02	0·751	5 to 6″
		Mean ..	0·737	
0·4992	309·55	228·88	0·739	2′
	1257·49	983·16	0·781	10′
	1257·49	983·16	0·781	1′
		Mean ..	0·783	
Edges rounded.	298·38	228·88	0·774	2′
	602·32	442·58	0·740	5 to 6″
		Mean ..	0·757	
	General Mean		0·740	

EXPERIMENTS UPON THE FRICTION OF OOLITIC LIMESTONE UPON OOLITIC LIMESTONE, WHEN THE SURFACES HAVE BEEN SOME TIME IN CONTACT WITH A BED OF FRESH MORTAR.

Surface of Contact.	Pressure, Q.	Motive Effort or Friction, F.	Ratio of Friction to Pressure, f.	Time of Contact.
sq. ft.	lbs.	lbs.		
0·8611	325·66	253·98	0·780	10′
	506·08	404·87	0·800	10′
	783·98	580·87	0·740	15′
	783·98	608·22	0·773	10′
	783·98	555·73	0·709	10′
	1167·73	983·16	0·841	15′
		Mean ..	0·773	
0·4992	309·55	239·21	0·772	10′
	489·97	379·74	0·775	10′
	781·10	568·30	0·727	10′
	1164·86	807·15	0·792	15′
	1164·86	907·74	0·779	10′
	1169·27	807·15	0·690	10′
	1548·61	1159·17	0·748	15′
		Mean ..	0·745	
0·1636	319·82	254·02	0·794	10′
	500·25	304·30	0·608	10′
	791·37	480·26	0·607	10′
	1161·90	731·69	0·629	15′
		Mean ..	0·659	
	General Mean		0·735	

These experiments show that the friction at starting is for these stones very nearly the same with the interposition of mortar as without.

In recapitulating, recent trials have caused us to see that the friction at the moment of starting, and after a very short time of contact, is—

1st. Proportional to the pressure.

2nd. Independent of the area of the surfaces of contact; and that furthermore, for compressible bodies, it is notably much greater than that which takes place during motion.

Observation relative to the Expulsion of Unguents under Heavy Pressures, and by Prolonged Contact.—We have observed metallic bodies with unguents of grease or oil, under very great pressure, compared to their surfaces, and find, after a contact of some duration, that the unguents are expelled, so that the surfaces are simply in an unctuous state, and thus have double the friction of surfaces well greased. This shows us why the effort required to put certain machines in motion is, disregarding the influence of inertia, often much greater than that required for maintaining a rapid motion, and proves that, for an experimental appreciation of the friction of machines in motion, we need not, as is sometimes done, make use of the same methods as for machines starting from repose.

Influence of Vibrations upon the Friction at Starting.—Another remarkable circumstance noted in the experiments at Metz is, that when a compressible body is solicited to slide by an effort capable of overcoming the friction of motion, but inferior to the friction at starting, a simple vibration, produced by an external and apparently a slight cause, may determine the motion. Thus, for oak rubbing on oak, the friction at starting is 0·680 of the pressure, and the friction during motion is 0·480; so that, to produce the motion of a weight of 2205 lbs. it is necessary then to exert an effort of 1500 lbs., while there is only needed 1059 lbs. to maintain it. Still, under an effort equal, or a little above 1059 lbs., and by the effort of a vibration, the body may be started.

This important observation applies to constructions always more or less exposed to vibrations, and shows that, if in the calculations for machines for producing motion, we should take into account the greatest value of the friction, we should in those relating to the stability of constructions, on the other hand, introduce its smallest value, that for motion. It seems, finally, to explain how it sometimes happens that buildings, for the stability of which no uneasiness was felt, have fallen at the passing of a wagon, and how the firing of salutes from a breach battery may, at certain times, accelerate the fall of a rampart or a building.

Influence of Unguents.—Fat unguents considerably diminish friction, and the consequent wear of surfaces. But from the observations made, p. 1575, we see that though the friction is in itself independent of the extent of the surfaces, it is well to proportion them to the pressures they are appointed to sustain, so that the unguents may not be expelled. We would also remark that all the experiments in consideration were made under pressures more or less considerable, and their results should only be applied to analogous cases. In fact, we may conceive that if the pressures were so great, in respect to the surfaces, as to occasion a marked defacement, the state of the surfaces, and consequently the friction, would vary; or that, on the contrary, if the surfaces were great, and the pressures very slight, the viscosity of the unguents, usually disregarded, might then exert a sensible influence.

We would observe that, in general, and especially for metals, pure water is a bad unguent, and often increases rather than diminishes the friction.

Adhesion of Mortar and Solidified Cements.—But, for mortars which have set and acquired a proper degree of dryness, there exists a different condition of things. Adhesion and cohesion take the place of friction, and the resistance to separation becomes sensibly proportional to the extent of the surface of contact, and independent of the pressure exerted, either at the moment of rest or that of separation.

For limestones bedded with mortar of hydraulic lime of Metz, the resistance is about 2112 lbs. per square foot of surface. With other limes, undoubtedly common, M. Boistard has found 1426 lbs. With plaster, the resistance seems to follow the same law; but it varies considerably with the instant of the setting of the plaster, which seems to exert a great influence upon the cohesion.

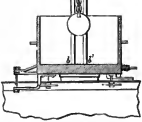
Observation upon the Introduction of Friction and Cohesion in Calculations upon the Stability of Constructions.—Finally, we would remark that friction cannot, in the case of beddings in mortar, or in plaster, show itself until the cohesion or adhesion is overcome, and that consequently these two resistances cannot coexist. In calculations upon the stability of structures, we should only reckon upon one of these, and that the weakest.

Experiments upon Friction during a Shock.—Poisson, in his Traité de Mécanique, expresses himself in these terms;—"Though no observations have been made upon the intensity of friction during a shock, we may suppose, by induction, that it follows the general laws of friction of bodies subjected to pressures, since percussion is only a pressure of very great intensity exerted during a very short time."

To verify by direct observation the correctness of this supposition, and at the express invitation of Peisson, Morin undertook many experiments, choosing for that purpose the case of strips of cast iron sliding upon bars of cast iron spread with lard, since this had been the subject of careful study in his preceding experiments, and is the case which most frequently occurs in practice.

Description of the Apparatus employed in the Experiments.—The apparatus which Morin employed differs from that described in p. 1570, only in the following disposition necessary for suspending to the sled, at a desired height, the body designed to produce the shock, and allowed to fall at will during the motion.

3048.



Upon the sides of the box of the sled, Fig. 3048, are raised two frames of firm uprights *a b* and *a' b'*, pierced with holes at intervals of ·16 ft., through which pass two iron pins; upon these pins rests a movable cross-piece *c d* of oak. By raising and lowering the pins, the height of the cross-piece *c d* above the sled may be varied at will. A screw *e* and nut passes freely across a hole cut in the middle of the cross-piece, and bears a plier with ring legs, upon which is suspended a shell to give the shock. The two legs of the pliers are bound with strips of wick with quick match, holding them shut. By means of the screw *e* the height of the shell above the surface shocked can be exactly regulated.

We may easily conceive from this description, the box and uprights being firmly fastened to the sled, that the whole system partakes of a common motion, and that if at any instant of its course the shell falls upon the sled, it falls there with a vertical velocity due to the height of the fall, and with a horizontal velocity which, as we shall see hereafter, was sensibly the same as that of the sled. By means of the ligature of the legs of the pliers we accomplish the fall of the shell, without any external concussion or disturbance. For this purpose a man sets fire to the match, and gives the signal for the starting of the sled; combustion is communicated to the upper part which keeps the pliers closed; these open suddenly and let loose the shell, without any possibility of disturbing the common motion of the system of the two bodies.

General Circumstances of the Experiments.—The experiments were made in impressing the sled, sometimes with a uniform, and sometimes with an accelerated motion. The first of these motions was obtained at will, by giving to the descending box a weight just sufficient to overcome the friction, and in suspending under this box a shell of 110 lbs. weight, which only descended 1·64 ft. when its action ceased. As for the accelerated motion, it was produced whenever the motive weight surpassed the friction. The law of these motions was moreover determined, in each case, by means of curves traced by the style of the chronometric apparatus.

General Examination of what occurred in these Experiments.—We can readily appreciate the mode of action during the experiments. We take, for example, a case where the system of the sledge and the shell suspended above it is impressed with a uniform motion. At the instant when the combustion of the wick allows the legs of the pliers to separate, the shell is free, and falls; during its fall, until the moment it reaches the sledge, the latter being freed from the weight of the shell, acquires an amount of motion precisely equal to what would be consumed by the friction due to this weight. The horizontal velocity of the sledge, at the instant of the shock, is then a little greater than that of the shell. After this the forces of compression developed by the shock produce a friction variable as themselves, at each instant, which consumes a certain quantity of motion; so that the sledge, whose progress was accelerated during the fall of the shell, is afterwards retarded during the action of the shock.

Formulæ employed in Calculating the Results of the Experiments.—As it is desirable to prove whether the friction remained proportional to the variable pressures produced during the short intervals of the phenomena, we proceed to give some formulæ relative to this hypothesis, which we will hereafter compare with the results of experiment. We consider first the case of uniform motion, and call

Q the weight of the sledge, and the suspending apparatus of the shell;
q the weight of the shell producing the shock;
f the ratio of friction to the pressure for the surfaces in contact;
h the height of fall of the shell above the sledge;
U the velocity due to this height;
T the time of the fall;
V the horizontal velocity of the sledge and shell at the instant when the latter is let loose by the pliers;
V′ the velocity of the body after the shock;
$g = 32 \cdot 1817$ ft.

At the instant when the shell is freed, the quantity of motion of the system is $\frac{Q + q}{g} V$.

The weight of the shell, when connected with the sledge, produces a friction $f q$ which, in each element of time t, consumes a quantity of motion $f q t$, and which, during the time of the fall, would consume the quantity $f q T$.

But since, on the other hand, the shell ceases to press upon the sledge during this time, it follows that the quantity of motion gained by the system by reason of this diminution of pressure, is precisely $f q T$.

At the instant when the shell reaches the sledge, the quantity of motion possessed by the system is then $\frac{(Q + q) V}{g} + f q T$.

From this instant, and during the whole period of the shock, the shell loses, in each element of time, an element of velocity, and consequently a quantity of motion $\frac{q}{g} u$, whence results a force of compression $\frac{q}{g} \times \frac{u}{t}$, producing a friction $\frac{fq}{g} \times \frac{u}{t}$. This friction consumes in an element of time a quantity of motion $\frac{fq}{g} \cdot \frac{u}{t}$, and when all relative motion in a vertical direction is destroyed, the friction due to the forces of compression has finally consumed a quantity of motion equal to $\frac{fq}{g}$ U.

Consequently, when the shock has terminated, we should have between the quantities the relation $\frac{(Q + q) V}{g} + f q T - \frac{f q U}{g} = \frac{Q + q}{g} V$, or $f q g T - f q U = (Q + q)(V' - V)$.

Now, the shell falling with a uniformly accelerated motion by virtue of gravity, we have, evidently, $U = g T$, whence it follows that $V = V'$; that is to say, that in our apparatus the quantity of motion destroyed by the friction resulting from the forces of compression must be precisely equal to that which it gains during the fall of the shell.

These two effects are successive, but take place in a short interval of time, and therefore occasion in the curve of motion undulations in opposite directions, which do not affect the general law, and are scarcely appreciable, either in the draughted curve or that made from the abstract of the Table.

The Acceleration of the Motion of the Sledge during the Fall of the Shell may be neglected.—It is easy to be assured *a priori* that the acceleration of the velocity of the sledge during the fall of the shell was always very small in our experiments, though the height of the fall has reached 1·97 ft. We observe, then, from what has just been said, that calling V_1 the horizontal velocity of the sledge at the moment when the shell reaches it, we shall have $\frac{Q}{g} V + f q T = \frac{Q}{g} V_1$, whence

$$V_1 - V = \frac{f q g T}{Q} = \frac{f q U}{Q}.$$

Making, for example, $q = 110{\cdot}27$ lbs., $h = 1{\cdot}968$ ft., and $U = 13{\cdot}80$ ft., $Q = 590{\cdot}68$ lbs., $f = 0{\cdot}071$, which answers to one of the most intense shocks produced during the experiments, we find $V_1 - V = 0{\cdot}1829$ ft.

Now, the shock of the shell in the horizontal direction taking place only in virtue of this difference in velocity, we see that its effect upon the general motion should be quite insensible, and we may, as we have done in the preceding calculation, neglect its influence upon the general motion of the sledge.

Case where the Motion of the Sledge is Accelerated.—The preceding reasoning applies to the case where the system of the shell and of the sledge is impressed with an accelerated motion, and it follows that if, as we have admitted, the friction during the shock remains proportional to the pressure, the general law of motion in our apparatus cannot be affected; or, in other words, that if, before the fall of the shell, the motion is uniform or accelerated, according to a certain law, it will still be so after the shock, according to the same law. The only disturbance which will result will be sometimes manifested by undulations, which, in most cases, would hardly be appreciable. Moreover, the hardness or compressibility of the body in contact should not have any influence upon the result, and in causing the shell to fall upon the beechwood joists composing the sledge, or upon a mass of soft loam placed upon it, we should, for circumstances otherwise similar, find the same law of motion, which should be the same as though there had been no shock.

Results of Experiments.—It remains now for us to compare the results of the formulæ with those of experiments which have been made, some when the sledge was impressed with a uniform motion, and some when the motion was accelerated. In these experiments we have varied the weight of the shells imparting the shock from 26·43 lbs. to 110 lbs., or nearly 1 to 4; the ratio of the weight of the body imparting the shock to that of the body shocked, from $\frac{1}{18}$ to $\frac{1}{4}$, and the height of the fall from 0·328 ft. to 2·29 ft., or from 1 to 7. The shock was produced upon wood, and upon loam placed upon the sledge. If, then, the laws which we have admitted in the preceding formulæ are verified by experiments within such extended limits, we may conclude that they subsist for pressures developed during the shock, as well as for others without shocks.

EXPERIMENTS UPON THE FRICTION OF CAST IRON UPON CAST IRON, WITH AN UNGUENT OF LARD DURING THE SHOCK.

Weight of the Sledge.	Weight of the Sphere.	Total Pressure, $Q+q$.	Height of Fall of the Sphere, h.	Motive Weight during Uniform Motion.	Friction, F.	Ratio of Friction to Pressure, f.	Velocity of Uniform Motion.	Remarks.
lbs.	lbs.	lbs.	feet.	lbs.	lbs.		feet.	
492·30	26·42	518·72	0·328	41·312	39·264	0·075	2·761	No shock.
			0·328				2·624	
			0·328				2·715	
			0·984				2·643	
			0·984				2·682	
478·26	26·42	504·68	1·968	37·708	35·832	0·071	2·460	
	26·42	504·68	1·968	37·708	35·832	0·071	2·558	
	55·13	533·39	0·984	40·887	38·843	0·072	2·534	
	55·13	533·39	0·984	40·887	38·843	0·072	2·678	
	55·13	533·39	0·984	40·887	38·843	0·072	2·755	
	55·13	533·39	1·968	40·887	38·843	0·072	2·797	
	55·13	533·39	1·968	40·887	38·843	0·072	2·659	
	55·13	533·39	1·968	40·887	38·843	0·072	2·624	No shock.
	55·13	533·39	1·968	40·887	38·843	0·072	2·656	
	55·13	533·39	2·952	40·887	38·843	0·072	2·672	
	55·13	533·39	2·952	40·887	38·843	0·072	2·814	No shock.
	110·27	588·53	0·984	44·946	42·698	0·072	3·033	
	110·27	588·53	1·968	44·946	42·698	0·072	2·961	
	110·27	588·53	1·968	44·946	42·698	0·072	3·043	

Note.—The shock is produced by the fall of a cast-iron sphere upon beech joists, while the system slides with a uniform motion.

EXPERIMENTS UPON THE FRICTION OF CAST IRON UPON CAST IRON, WITH AN UNGUENT OF LARD DURING THE SHOCK.

Weight of the Sledge.	Weight of the Sphere.	Total Pressure, $Q + q$.	Height of Fall of the Sphere, h.	Motive Weight during Uniform Motion.	Friction, F.	Ratio of Friction to Pressure, f.	Velocity of Uniform Motion.	Remarks.
lbs.	lbs.	lbs.	feet.	lbs.	lbs.		feet.	
590·68	55·12	646·83	0·98	48·16	45·94	0·071	2·829	
			0·98				2·744	
			..				2·427	No shock.
			..				2·460	
			1·96				2·576	
			..				2·935	No shock.
			2·95				2·547	
			2·95				2·347	
			2·95				2·702	
			0·98				2·328	
			0·98				2·853	
590·68	110·24	700·96	1·97	52·36	49·74	0·071	2·675	No shock.
							2·853	

Note.—The shock is produced by the fall of a sphere upon a mass of loam, while this mass and the sledge slide with a common uniform motion.

We see by these Tables that the velocity of uniform motion has been the same in the experiments made with the shocks as in those without them, whatever may have been the height of the fall. This velocity, in all cases, has depended solely upon the load or total pressure of the motive weight and the state of the surfaces.

An examination of the curves of motion shows from the vibrations produced by the shock throughout the apparatus—which are felt even at the style—in what place the shock was produced, and whether it occurred in the period of its course, when the motion had become uniform, or in that when it was accelerated, the draughted curve and the abstract of the Tables afford but slight undulations, and the motion remains or becomes uniform with the same velocity.

Finally, these experiments show that in the shock the frictions due to the pressures developed are still proportional to these pressures and independent of the velocity.

Friction of Journals.—Besides the experiments previously reported upon the friction of plane surfaces, Morin has made a great number upon that of journals by means of a rotating dynamometer with a plate and style.

The axle of this dynamometric apparatus was hollow and of cast iron. It could receive, by means of holders exactly adjusted, a change of journals of different materials and diameters. Its load was composed of solid cast-iron discs weighing 331 lbs. each, whose number could be increased so as to attain a load of more than 3042 lbs. A pulley, the friction of whose axle was slight, and which transmitted the motion by the intervention of a spring, received by a belt, the motion of a hydraulic wheel, and the difference of tension of the two parts of the belt was measured by the dynamometer with the style.

Journals were from ·11 to ·22 ft. in diameter. The velocities varied in the ratio of 1 to 4. The pressures reached 4145 lbs., and within these extended limits we have proved that the friction of journals is subject to the same laws as that of plane surfaces. But it is proper to observe that from the form itself of the rubbing body the pressure is exerted upon a less extent of surface, according to the smallness of the diameter of the journal, and that unguents are more easily expelled with small than with large journals.

This circumstance has a great influence upon the intensity of friction, and upon the value of its ratio to the pressure. The motion of rotation tends of itself to expel certain unguents, and to bring the surfaces to a simply unctuous state. The old mode of greasing, still used in many cases, consisted simply in turning on the oil, or spreading the lard or tallow upon the surface of the rubbing body, and in renewing the operation several times in a day.

We may thus, with care, prevent the rapid wear of journals and their boxes; but, with an imperfect renewal of the unguent, the friction may attain ·07, ·08, or even ·1 of the pressure.

If, on the other hand, we use contrivances which renew the unguents without cessation in sufficient quantities, the rubbing surfaces are maintained in a perfect and constant state of lubrication, and the friction falls as low as ·05 or ·03 of the pressure, and probably still lower. The polished surfaces operated in these favourable conditions became more and more perfect, and it is not surprising that the friction should fall far below the limits above indicated.

These reflections show how useful are oiling fixtures in diminishing the friction, which, in certain machines, as mills with complicated mechanism, consume a considerable part of the motive work. We cannot, then, too much recommend the use of appliances to distribute the unguent continuously upon the rubbing surfaces of machines, and it is not surprising that a great number of dispositions have been proposed for this purpose within a few years. We should be careful to select those which only expend the oil during the motion, excluding those which feed by the capillary action of a wick of thready substances. These constantly drain the oil even during the repose of the machine, thus consuming it at a pure loss.

EXPERIMENTS UPON THE FRICTION OF CAST-IRON JOURNALS UPON CAST-IRON BEARINGS.

Diameter of Journals.	Nature of Unguent.	Velocity of the Circumference in 1".	Weight of the Axle and its Load.	Ratio of the Friction to the Pressure.	Remarks.
feet.		feet.	lbs.		
0·328	Oil.	0·136 0·222 0·488 0·445 0·345	2269·4	0·082 0·082 0·082 0·079 0·079 0·081	In these experiments the oil was poured only upon the surface of the journals.
0·328	Oil.	0·212 0·262 0·409 0·488	2269·4	0·054 0·052 0·052 0·052	In these experiments the oil was poured ceaselessly upon the rubbing surfaces.
			Mean	0·053	
0·177	Oil.	0·429 0·409 0·465	2241·8	0·101 0·109 0·101	In these experiments the oil was expelled by the pressure, and the surfaces were simply very unctuous.
			Mean	0·104	
0·177	Lard.	0·190 0·268 0·328 0·393 0·445 0·465	2240·7	0·070 0·069 0·075 0·084 0·070 0·060	In these experiments the surfaces themselves supplied the lard.
0·328	Lard.	0·222 0·331 0·380 0·409 0·429	4157·	0·049 0·050 0·052 0·040 0·042	In these experiments the unguent was renewed.
0·328	Lard.	very slow 0·150 0·238 0·321 0·321 0·380 0·492	2276·	0·037 0·039 0·025 0·026 0·035 0·026 0·832	In these experiments the unguent was continually renewed.

The examples contained in this Table suffice to show that the friction of journals is in itself subject to the same laws as that of plane surfaces; but they also show the great influence which the constant renewal of the unguent possesses in diminishing the value of the ratio of the friction to the pressure, which sometimes falls as low as ·025.

We see also that the diameter of the journals seems to have some influence upon the more or less complete expulsion of the unguent, and consequently upon the friction, so that the dimensions to be given them should not be determined from a consideration solely of their resistance to rupture.

Recapitulating the summary of the experiments which Morin has made upon the friction of journals shows that it is nearly the same for woods and metals rubbing upon each other, and that its ratio to the pressure may, according to the case, take the values given in the following Tables.

STATE OF SURFACES.

With rotten-stone and perfectly greased. *f*.	Continually supplied with unguent. *f*.	Greased from time to time. *f*.	Unctuous. *f*.
0·025 to 0·030	0·050	0·07 to 0·08	0·150

Advantage of Granulated Metals.—It is not true, as is generally supposed, that the friction is always less between substances of different kinds than between those of the same kind. But it is well generally to select for the rubbing parts granulated rather than fibrous bodies, and especially not to expose the latter to friction in the direction of the fibres, because the fibres are sometimes raised and torn away throughout their length. In this respect fine cast iron, which crystallizes in round grains, as well as cast steel, are very suitable bodies for parts subjected to great friction.

Thus, for several years past, a cast-iron packing has come into very general use for the pistons of steam-engines. If for the boxes of iron or cast-iron axles, brass continues in use, it is chiefly because it is less hard, and wears out before the axles, and because it is easier to replace a box than an axle.

Remarks upon very light Mechanisms.—In very light mechanisms, and especially with very rapid motion, the viscosity of the unguent may offer a resistance similar to that produced by friction proper; in such cases the results of experiments made under considerable pressures in relation to the surfaces of contact, should only be applied with extreme caution.

Use of the Results of Experiments.—The results obtained from the experiments of Morin are resumed in the three following Tables, which give the ratio of the friction to the pressure, for all the substances employed in construction. The first of these Tables relates to plane surfaces which have been some time in contact. The values which it gives for the ratio *f* of friction to the pressure, should be employed whenever we are to determine the effort necessary to produce the sliding of two bodies which have been some time in contact. Such is the case with the working of gates and their fixtures, which are used only at intervals more or less distant.

I.—FRICTION OF PLANE SURFACES WHICH HAVE BEEN SOME TIME IN CONTACT.

Kind of Surfaces in Contact.	Disposition of the Fibres.	Condition of the Surfaces.	Ratio of Friction to Pressure, *f*.
Oak on oak	Parallel	Without unguent	0·62
	,,	Rubbed with dry soap	0·44
	Perpendicular	Without unguent	0·54
	,,	Moistened with water	0·71
	Wood upright on wood flatwise	Without unguent	0·43
Oak on elm	Parallel	,,	0·38
Elm on oak	,,	,,	0·69
	,,	Rubbed with dry soap	0·41
	Perpendicular	Without unguent	0·57
Ash, pine, beech, on oak	Parallel	,,	0·53
Tanned leather on oak	The leather flatwise The leather on edge	,,	0·61
		,,	0·43
		Moistened with water	0·79
Black curried leather or belt on plane oak surface	Parallel	Without unguent	0·74
Black curried leather or belt on oak drum	Perpendicular	,,	0·47
Hemp matting on oak	Parallel	,,	0·50
		Moistened with water	0·87
Hemp cord on oak	,,	Without unguent	0·80
Iron on oak	,,	,,	0·62
		Moistened with water	0·65
Cast iron on oak	,,	,,	0·65
Brass on oak	,,	Without unguent	0·62
Ox-hide for piston packing on cast iron	Flatwise	Moistened with water	0·62
	On edge	With oil, lard, tallow	0·12
Black curried leather, or belt upon cast-iron pulley	Flatwise	Without unguent	0·28
		Moistened with water	0·38
Cast iron upon cast iron	,,	Without unguent	0·16*
Iron upon cast iron	,,	,,	0·19
Oak, elm, yoke elm, iron, cast iron, and brass, sliding two and two one upon the other	,,	Spread with tallow	0·10†
		With oil, or lard	0·15‡
Calcareous oolite upon oolite limestone	,,	Without unguent	0·74
Hard calcareous stone called muschelkalk upon oolite limestone	,,	,,	0·75
Brick on calcareous oolite	,,	,,	0·67
Oak on ,, ,,	Wood upright	,,	0·63
Iron on ,, ,,	,,	,,	0·49
Hard muschelkalk on muschelkalk	,,	,,	0·70
Calcareous oolite upon ,,	,,	,,	0·75
Brick on muschelkalk	,,	,,	0·67
Iron upon ,,	,,	,,	0·42
Oak on ,,	,,	,,	0·64
Calcareous oolite on calcareous oolite	,,	With mortar, three parts fine sand, and one part of hydraulic lime	0·74§

* The surfaces being somewhat unctuous.

† When the contact had not been long enough to press out the unguent.

‡ When the contact had been long enough to press out the unguent and bring the surfaces to an unctuous state.

§ After a contact of from ten to fifteen minutes.

II.—Friction of Plane Surfaces in Motion upon each other.

Surfaces in Contact.	Position of Fibres.	State of Surfaces.	Ratio of Friction to Pressure, *f*.
Oak on oak	Parallel	Without unguent	0·48
	„	Rubbed with dry soap	0·16
	Perpendicular	Without unguent	0·34
	„	Wet with water	0·25
	Upright on flatwise	Without unguent	0·19
Elm on oak	Parallel	„	0·43
	Perpendicular		0·45
	Parallel		0·25
Ash, pine, beech, wild pear, on oak	„	„	0·36 to 0·40
Iron on oak	„	„	0·62
		Wet with water	0·26
		Rubbed with dry soap	0·21
Cast iron on oak	„	Without unguent	0·49
		Wet with water	0·22
		Rubbed with dry soap	0·19
Copper on oak	„	Without unguent	0·62
Iron on elm	„	„	0·25
Cast iron on elm	„	„	0·20
Black curried leather on oak	„	„	0·27
Tanned leather on oak	Flatwise on edge	„	0·30 to 0·35
		Wet with water	0·29
Tanned leather upon cast iron and brass	Flatwise and on edge	Without unguent	0·56
		Wet with water	0·36
		Unctuous and wet with water	0·23
		Spread with oil	0·15
Hemp strips or cords upon oak	Parallel	Without unguent	0·52
	Perpendicular	Wet with water	0·33
Oak and elm on cast iron	Parallel	Without unguent	0·38
Wild pear on cast iron	„	„	0·44
Iron upon iron	„	„	*
Iron upon cast iron and brass	„	„	0·18†
Cast iron on cast iron and brass	„	„	0·15†
Cast iron on cast iron	„	Wet with water	0·31
Brass on brass	„	Without unguent	0·20
Brass on cast iron			0·22
Brass on iron			0·16‡
Oak, elm, yoke elm, wild pear, cast iron, iron, steel, steel and brass, sliding upon each other or themselves	„	Lubricated in the usual way with tallow, lard, soft coom, &c.	0·7 to 0·8§
Calcareous oolite on calcareous oolite	„	Slightly unctuous to the touch	0·15
		Without unguent	0·64
Muschelkalk upon „ „	„	„	0·67
Common brick upon „ „	„	„	0·65
Oak on oolitic limestone	Wood upright	„	0·38
Forged iron upon oolitic limestone	Parallel	„	0·69
Muschelkalk upon muschelkalk		„	0·38
Oolitic limestone upon „		„	0·65
Common brick on „		„	0·60
Oak on „	Wood upright	„	0·38
Iron on „	Parallel	„	0·24
		Wet with water	0·30

* Surfaces worn when there was no unguent.
† The surfaces still being slightly unctuous.
‡ The surfaces slightly unctuous.
§ When the unguent is constantly supplied, and uniformly laid on, this ratio may be lowered to 0·05.

Table II. relates to plane surfaces in motion upon each other; Table III. applies to journals in motion upon their bearings. The values given by these Tables ought not to be used except to calculate the friction of two surfaces in motion upon each other, after the period in which the coefficient of friction at the starting has been introduced.

III.—FRICTION OF JOURNALS IN MOTION UPON THEIR PILLOWS.

Surfaces in Contact.	State of Surfaces.	Ratio of Friction to the Pressure when the Unguent is renewed.	
		In the Common Way.	Continuously.
Cast-iron journals on cast-iron bearings	Unguents of olive oil, of lard, of tallow, or of soft coom	0·07 to 0·08	0·030 to 0·054
	With the same unguents and moistened with water	0·08	..
	Asphalte	0·054	..
	Unctuous	0·14	..
	Unctuous and wet with water ..	0·14	..
Cast-iron cushions on brass cushions	Unguents of olive oil, of lard, of tallow, and of soft coom	0·07 to 0·08	0·03 to 0·054
	Unctuous	0·16	..
	Unctuous and wet with water ..	0·16	..
	Slightly unctuous	0·19	*
Cast-iron journals on lignum-vitæ bearings ..	Without unguent	0·18	†
	Unguents of oil or lard	..	0·090
	Unctuous with oil or lard	0·10	..
	Unctuous, with a mixture of lard and black-lead	0·14	..
Wrought-iron journals on cast-iron bearings	Unguents of olive oil, tallow, lard, or soft coom	0·07 to 0·08	0·030 to 0·054
Wrought-iron journals on brass bearings	Unguents of olive oil, tallow, lard	0·07 to 0·08	0·030 to 0·054
	Unguents of soft coom	0·09	..
	Unctuous and wet with water ..	0·19	..
	Slightly unctuous	0·25	‡
Iron journals on lignum-vitæ bearings	Unguents of oil or lard	0·11	..
	Unctuous	0·19	..
Brass journals on brass bearings	Unguents of oil	0·10	..
	Unguents of lard	0·09	..
Brass journals on cast-iron cushions	Unguents of oil or tallow	..	0·030 to 0·052
Lignum-vitæ journals on cast-iron cushions	Unguents of lard	0·12	..
	Unctuous	0·15	..
Lignum-vitæ journals on lignum-vitæ cushions ..	Unguent of lard	..	0·07

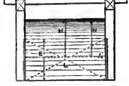
* The surfaces began to wear. † The wood being slightly unctuous. ‡ The surfaces began to wear away.

Application to Gates.—Let L be the horizontal width of a gate under a certain head of water, and H′ the head or height of level above a horizontal section of this gate, of a thickness h' infinitely small. The pressed surface of this element will be L h', and the pressure which it will experience will be 63·32 L H′ h'. The total pressure upon the entire surface of the gate being equal to the sum of all the similar pressures upon each of the elements, will have for its value

$$62 \cdot 32\, L (H' h' + H'' h'' + H''' h''' + \&c.).$$

Now, the products L H′ h', L H″ h'', &c., are the moments of the elementary surfaces L h', L h'', &c., in relation to the plane of the level, and their sum is equal to the moment of the whole surface equal to L E H. Calling E the height of the gate pressed, and H the distance of the centre of gravity from the surface of the level, or the head upon the centre of the figure. Then the total pressure is 62·32 L E H, and the friction which results against the slides of this gate is 62·32 f . L E H, f being the ratio of the friction to the pressure for the surfaces in contact, a ratio whose value should be taken from the first Table, if we are to calculate the effort required to put the gate in motion.

3049.



Example.—If L = 6·56 ft., Fig. 3049, E = 1·148 ft., H = 4·92 ft., the first Table gives for a wood gate of oak sliding with crossed fibres upon oak wet with water $f = 0 \cdot 71$; we have then for the friction 62·32 × 0·71 × 6·56 × 1·148 × 4·92 ft. = 1639·4 lbs.

The effort should be transmitted in the direction of the racks fixed upon the gate; and as it is considerable, it will be proper to arrange a kind of screw-jack, suitably proportioned, for the establishment of which we may take as the effort to be exerted by a man upon the winch, at any instant, from 55 to 66 lbs. at most, and during the motion from 22 to 26·5 lbs.

When the gate is in motion, the effort to be transmitted to the racks is much less, because the ratio of the friction to the pressure diminishes, and is reduced for a gate with moistened slides to 0·25, which gives for the friction during motion,

$$62\cdot32 \times 0\cdot25\,L\,E\,H = 62\cdot32 \times 0\cdot25 \times 6\cdot56 \times 1\cdot148 \times 4\cdot92 = 577\cdot2 \text{ lbs.},$$

at the first instant, and a value decreasing with the raising of the gate, or as the head H upon its centre is lessened.

We hardly need to say that, in working the gate, we must calculate for the maximum effort.

Application to Saw-frames.—If we have, for example, the frame of a saw for veneering, subjected to a pressure of 110·274 lbs., and provided with iron strips sliding in brass grooves, greased with lard, we have, if the surfaces are well lubricated, for the friction, $0\cdot07 \times 110\cdot274 = 7\cdot719$ lbs., and if they are unctuous, $0\cdot15 \times 110\cdot274 = 16\cdot54$ lbs.

If the stroke of the frame is 3·936 ft., and the number of strokes 180 in 1′, the space described in 1″ will be 11·81 ft., and the work consumed by the friction of the frame in 1″ will be in the first case, $2 \times 11\cdot81 \times 7\ 719 = 182\cdot32$ lbs. ft. $= \frac{1}{3}$ horse-power nearly; in the second case,

$$2 \times 11\cdot81 \times 16\cdot54 = 390\cdot66 \text{ lbs. ft.} = \frac{2}{3} \text{ horse-power nearly.}$$

Application to Journals.—To calculate the work consumed by the friction of the journals of a revolving axle, we begin by seeking the resultant of the forces acting around this axle, and decompose this into two, the one horizontal and the other vertical, and we take separately the resultant of each of these groups. Calling X the sum of the horizontal components, Y the sum of the vertical components, the general resultant will be $\sqrt{X^2 + Y^2}$, and the friction produced by it will be $f . \sqrt{X^2 + Y^2}$.

The theorem of Poncelet, already cited, informs us that when we do not know the order of magnitude of X and Y, we may calculate to nearly $\frac{1}{6}$ of the value of the radical by the formula $0\cdot83\,(X + Y)$, and that if we know beforehand that one of the terms, X for example, is greater than the other, which is most usually the case, we shall have the value of the radical to $\frac{1}{25}$ nearly, by the expression $0\cdot96\,X + 0\cdot4\,Y$.

Suppose, for example, that we have a hydraulic bucket-wheel weighing 88,219 lbs., transmitting a useful effect of 50 horse-power to the exterior circumference, and, imparting motion to a pinion, so that the useful resistance may be horizontal and represented by Q. Suppose the radius of the wheel $R = 9\cdot84$ ft., the velocity at its circumference to be 5·249 ft., and the radius of the gearing wheel $R' = 6\cdot56$ ft. The effort P transmitted to the circumference of the wheel will be

$$P = \frac{50 \times 550}{5\cdot249} = 5239 \text{ lbs.}$$

The pressure upon the journals of the hydraulic wheel will be $\sqrt{(M + P)^2 + Q^2}$, or, since $M = 88219$ lbs., and consequently $M + P$ is greater than Q, we may take for an approximate value of the radical to $\frac{1}{25}$ nearly, $0\cdot96\,(M + P) + 0\cdot4\,Q$.

For uniform motion, the moment of the power P must be equal to the sum of the moments of resistances. We have then, in calling r the radius of the journal $= 0\cdot393$ ft., $f = 0\cdot07$,

$$5239 \text{ lbs.} \times 9\cdot84 = Q \times 6\cdot56 + 0\cdot96\,(0\cdot07)\,(88219 + 5239)\,(0\cdot393) + 0\cdot4\,(0\cdot07)\,(Q \times 0\cdot393);$$

$$\text{whence } Q = \frac{5239 \times 9\cdot84 - 0\cdot96 \times 0\cdot07 \times 93458 \times 0\cdot393}{6\cdot56 \times 0\cdot4 \times 0\cdot07 \times 0393} = 7469 \text{ lbs.},$$

while if we had neglected the friction of the journals, we should have found

$$Q = \frac{5239 \times 9\cdot84}{6\cdot56} = 7858\cdot6 \text{ lbs.}$$

The velocity of the gearing wheel being $5\cdot249 \times \frac{2}{3} = 3\cdot499$ ft. The work transmitted to this circumference in 1″ is $7469\cdot8$ lbs. $\times\ 3\cdot499 = 26137$ lbs. ft. $= 47\cdot5$ horse-power. The loss by the friction of the journals is then $50\cdot00$ horse-power $- 47\cdot5 = 2\cdot5$ H. P.

If the surfaces of the journals had not been unctuous the loss would have been double.

The space described by the rubbing points, being one of the factors of work consumed by the passive resistance, it is important to diminish it as much as possible, and consequently to give the journals only such dimensions as will ensure a proper strength.

To calculate their diameter in the establishment of the wheel, we disregard the friction, which will give us a first value of $Q = 7858$ lbs., a little too much, and consequently for the resultant of the efforts to which the journal is subjected, $\sqrt{(93458)^2 + (7858\cdot6)^2} = 93787$ lbs.

Each journal supports then nearly 46893 lbs. of pressure, and its diameter, calculated by the formula for journals of hydraulic wheels, will be $d = \cdot00364 \sqrt{46893}$; whence $d = 0\cdot788$ ft.

This is the value which we have adopted in the preceding calculation.

C. Schiele's Anti-friction Curve.—This invention consists in the application of a curved form (instead of a rectilinear form usually employed) to the construction of cocks and valves, and also to the construction of axles, journals, bearings, or other rubbing surfaces in machinery in general, in order to reduce their friction and consequent wear and tear.

Fig. 3050 represents a plan and end view of a small apparatus for describing such a curve.

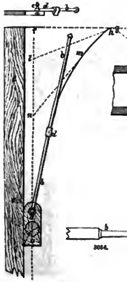
a a is a small wooden slide, to which the rod *b b* is jointed by means of a pin *c*. *d* is a slide or bush, to which a drawing pen is affixed, and *e e* is a ruler, along the edge of which the slide *a* is to be guided. If the slide *a* and rod *b b* be so placed that the pin *c* shall be at *f* and the pen *d* at the point *g*, the centre line at the rod *b b* will then be over the dotted line *g f*, at a right angle with the dotted line *l n*; and if the slide *a* be then guided along the edge of the ruler *e e* the pin *c* will move along the dotted line *l n*, dragging the pen *d* after it, which in travelling over a horizontal plane will describe the curved line *h m*. The pen *d* can be moved upon the rod *b* to the proper distance for the curve required, and is kept in that and in a vertical position by a spring which fits in a groove. *l n* is the axis of the curve, and *g f*, *h l*, *m n*, represent some of the tangents above mentioned.

Fig. 3051 represents a vertical section of the shell of a stop-cock, showing the application of this invention to the seats or surfaces of contact. The dotted lines near the top of the plug *a* represent a groove in the plug for the reception of a key.

Fig. 3052 represents the application of this curve to the seats or surfaces of contact of lift-valves for pumps.

Fig. 3053 shows its application to the journal and bearing of a regulator for a locomotive engine, to be used instead of a stuffing box. *a* is part of the boiler of a locomotive engine; *b* is the spindle of the regulator, and *c* is the journal; *d* is the bearing, and *e* is the lever or handle by which the regulator is turned. The spindle *b* is furnished on that end which is inside the boiler with a square hole for the reception of the squared end of a rod *g*, which has to transmit the motion to the valve.

3050.



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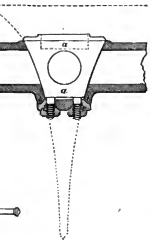

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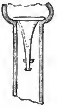

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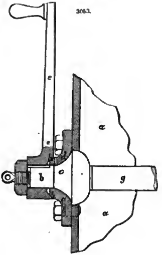

3056.

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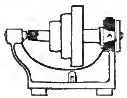

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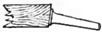

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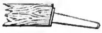

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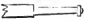
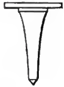


Fig. 3054 shows the application of Christian Schiele's curve to the journals and centres of turning lathes.

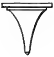
Figs. 3055, 3056, show the application to axles on the parts *a*, *b*, *c*. Here the pressure acts only at intervals in the direction of the axis, and must therefore be borne separately. The difference of their construction from that commonly in use will be seen on comparing Figs. 3055, 3056, with Figs. 3057, 3058.

Figs. 3059, 3060, show the application of this curve to pivots or axes for astronomical, or surveying, or other such instruments for comparison; see Fig. 3061, which shows a mode of construction now commonly in use. The curved form, as shown in Fig. 3060, is also applicable to footsteps of upright shafts.

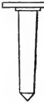
3059.



3060.



3061.



3062.

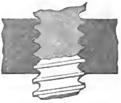
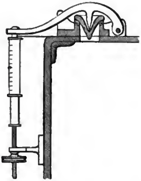


Fig. 3062 shows the application of this invention to the construction of the threads of screws. When the pressure against the surfaces to be constructed in the mode described acts in the direction of the axes of such surfaces, then Schiele commences the construction of the curve with that part which is shown in Fig. 3050 at *g*; for examples, see Fig. 3051, at *b*, *c*, and *d*; Figs. 3052, 3053, at *c*, *d*, and *i*; Figs. 3055, 3056, at *a*, *b*, *c*; Fig. 3060 and Fig. 3062. When part of the pressure acts from the side we have to commence with such a part of the curve which in its inclination to the axis would give the best resistance to the middle pressure of the combined forces; for examples, see Fig. 3051 at *a*; Fig. 3053 at *h h*; Fig. 3054 at *a* and *b*, and Fig. 3059.

Fig. 3063 shows the application of Schiele's curve to a safety-valve. Fig. 3064 to a lock-up safety-valve. Fig. 3065 to the feed-cock of a pump. Fig. 3066 a universal cock adjustable at any angle down to a right angle. Fig. 3067 the journal of a screw propeller. Fig. 3068, turning joint for pipes of oscillating engines. Fig. 3069, axis for astronomical instruments; also applicable to swing-bridges. Fig. 3070, pivot for turn-tables. Fig. 3071, pivot for shafting. Fig. 3072, pivot for sluice-doors. Fig. 3073, pivot for a journal for lathe-spindle. Fig. 3074, castor. Fig. 3075, cart axle-tree. Fig. 3076, joint of rods for boring Artesian wells. Fig. 3077, screw-collar. Fig. 3078, pivot for Archimedian screw. Fig. 3079, worm and wheel. Fig. 3080, screw-jack. Fig. 3081, pivot with anti-friction metal.

3063.



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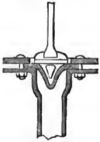

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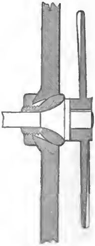

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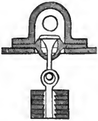

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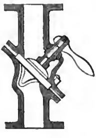

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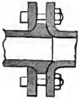

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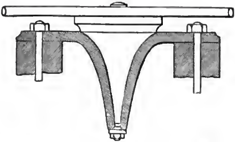

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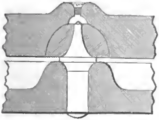

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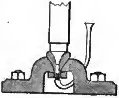

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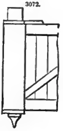

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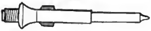

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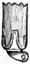

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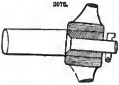

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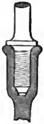

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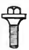

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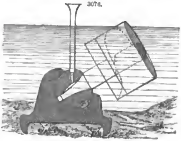

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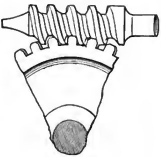
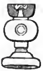
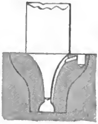


3080.

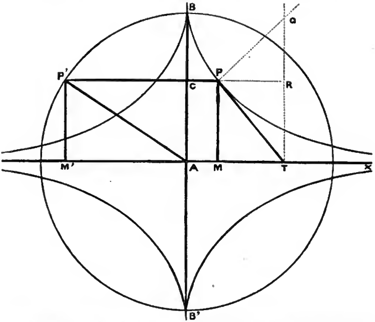


3081.



This curve, termed the anti-friction curve by Christian Schiele, is known to mathematicians as the *tractrix;* it has been erroneously identified with the *catenary.* This curve was invented by Christian Huygens and received its name from a supposition that it is the curve which would be described by a weight drawn on a plane by a string of a given length, the extremity of which is carried along the directrix A B, Fig. 3082. Euler has shown that this conclusion is wrong, unless the momentum of the weight which is generated by its motion be every instant destroyed. See Euler, *Nova.* Comm. Petrop. 1784. However, to Schiele is due the credit of applying this curve to effect an important mechanical requirement.

3082.



The characteristic property of the anti-friction curve, or tractrix, is that the locus of a point T, on the tangent P T, at a given distance from the point of contact, is a straight line A X, which is called the directrix of the curve.

To find the equation to the Anti-friction Curve.—Let the intercept (P T) of the tangent between the directrix A X and point of contact P be put = a. Then by the general formula for the subtangent

$$-\frac{y\,dx}{dy} = (a^2 - y^2)^{\frac{1}{2}}\ ; \qquad [1]$$

From integrating [1] we obtain

$$x = a \downarrow, \left(\frac{a + (a^2 - y^2)^{\frac{1}{2}}}{y}\right) - (a^2 - y^2)^{\frac{1}{2}}\ ; \qquad [2]$$

In general terms $\downarrow, (y)$ is put to represent the dual logarithm of y to the base B = 1·0000001; but $\frac{\downarrow, (y)}{10^8}$ corresponds with the hyperbolic log. of y to eight places of decimals. $\downarrow, (y) = \frac{\downarrow, (y)}{10^m}$, to any of the dual bases B_n or b_n, is termed the logarithm of y. Equation [1] may be found by differentiating [2], and thus verify the integration.

[2] may be put under the form

$$x = \downarrow, [a + (a^2 - y^2)^{\frac{1}{2}}] - a \downarrow, (y) - (a^2 - y^2)^{\frac{1}{2}}\ ;$$

$$\therefore\ \frac{dx}{dy} = -\frac{a\,y}{(a^2 - y^2)^{\frac{1}{2}}\,[a + (a^2 - y^2)^{\frac{1}{2}}]} - \frac{a}{y} + \frac{y}{(a^2 - y^2)^{\frac{1}{2}}}\ ;$$

$$\therefore\ -\frac{y\,dx}{dy} = \frac{a\,y^2}{a\,(a^2 - y^2)^{\frac{1}{2}} + (a^2 - y^2)} + a - \frac{y^2}{(a^2 - y^2)^{\frac{1}{2}}}\ ;$$

$$\text{and } -\frac{y\,d\,x}{d\,y} - a = \left[\frac{a\,y^2}{a + (a^2 - y^2)^{\frac{1}{2}}} - y^2\right]\frac{1}{(a^2 - y^2)^{\frac{1}{2}}}\,;$$

$$= \frac{a\,y^2 - y^2\left[a + (a^2 - y^2)^{\frac{1}{2}}\right]}{a + (a^2 - y^2)^{\frac{1}{2}}}\left(\frac{1}{(a^2 - y^2)^{\frac{1}{2}}}\right);$$

$$= -\frac{y^2}{a + (a^2 - y^2)^{\frac{1}{2}}}\,;\ \text{consequently,}$$

$$-\frac{y\,d\,x}{d\,y} = a - \frac{y^2}{a + (a^2 - y^2)^{\frac{1}{2}}} = \frac{a^2 + a\,(a^2 - y^2)^{\frac{1}{2}} - y^2}{a + (a^2 - y^2)^{\frac{1}{2}}} = (a^2 - y^2)^{\frac{1}{2}}\,.$$

The logarithms here employed may be found in any case without the use of tables. See 'Dual Arithmetic, a new Art,' by O. Byrne.

To find the equation of a tangent through any given point P on the Curve.—Let the co-ordinates of the given point be $x_1 =$ A M and $y_1 =$ M P.

$$\text{From [1]}\ \frac{d\,y}{d\,x} = -\frac{y}{(a^2 - y^2)^{\frac{1}{2}}}\,; \qquad [3]$$

Hence the equation to the straight line passing through P, and touching the curve at P, is

$$y - y_1 = -\frac{y_1}{(a^2 - y_1^2)^{\frac{1}{2}}}(x - x_1)\,; \qquad [4]$$

The geometrical construction for applying a tangent to the anti-friction curve is obviously pointed out by [4]. With the centre A and the radius $a =$ A B let a circle be described; through any point P of the curve let the ordinate P M be drawn, and P P′ parallel to A X, meeting the circle in P′, and let P′ A be drawn; a line P T parallel to P′ A is a tangent to the curve at P. For tangent of P′ A M′ $= \dfrac{y_1}{(a^2 - y^2)^{\frac{1}{2}}}$ = tangent of the angle P T M. It is evident that when $y = \pm a\ x = 0$, therefore if A B $= +\,a$ and A B′, Fig. 3082, $= -\,a$, the curve meets the axis of y at the points B, B′; and in [4], if $y_1 = \pm a$, and $x_1 = 0$, the equation becomes $x = 0$, which shews that the axis of y touches the curve at the points B, B′.

If [3] be differentiated, we have $d^2\,y = \dfrac{a^2}{(a^2 - y^2)^2}\,y\,d\,x^2$, hence, $d^2\,y$ and y have always the same sign, and the curve must be everywhere convex towards the directrix.

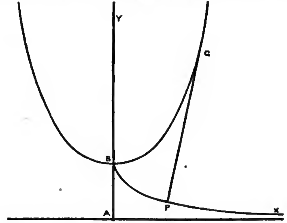
By [2] it appears that for each value of y there are two equal and opposite values of x, and for each value of x there are two equal and opposite values of y. Therefore the four branches of the curve, included in the four right angles round the origin A are perfectly equal and similar, and such as if placed upon each other would coincide. It also appears by equation [2] that, as x increases without limit, y diminishes without limit, and consequently the directrix A X is an asymptote.

To quadrate the Anti-friction Curve, from [1] we have $y\,d\,x = (a^2 - y^2)^{\frac{1}{2}}\,d\,y$. On one side of this equation, $y\,d\,x$ is the differential of the area A B P M; and since $-\,(a^2 - y^2)^{\frac{1}{2}} =$ A M′, = P′ C, the other side is the differential of the area B P′ C, and therefore taking the integrals of both sides we have P B A M = B P′ C. Also, since the triangle P′ A M′ = P T M, the area B P T A is equal to the sector B A P′. It also follows that the whole area included by the four branches is equal to the area of the circle B P′ B′. To rectify this curve, we find from [1], $-\dfrac{a\,d\,y}{y} = (d\,y^2 + d\,x^2)^{\frac{1}{2}}$ the general expression for the length of any plane curve referred to rectangular co-ordinates. The negative sign is appended to $\dfrac{a\,d\,y}{y}$, because the length of the arc increases as y diminishes. By integration we have $-\,a \rfloor,(y) + \mathrm{C} = \int (d\,x^2 + d\,y^2)^{\frac{1}{2}}$. To find the constant C, let the arc K be supposed to begin at B, so that when K = 0, $y = a$; hence $-\,a \rfloor,(a) + \mathrm{C} = 0$, $\therefore \mathrm{C} = a \rfloor,(a)$, and hence we find the length of the arc $\mathrm{K} = a \rfloor,\left(\dfrac{a}{y}\right)$. If $a = 3$ in. and $y = \cdot 3$ in.; then the length of the arc K = 6·90775527 in. For $\rfloor\left(\dfrac{3\cdot}{\cdot 3}\right) = \rfloor,(10) = 2{\cdot}30258509$; and $2{\cdot}30258509 \times 3 =$ 6·90775527 in. When K and y are given a can be found by dual arithmetic, but by no other known means.

Putting r for the radius of curvature at any point P, Fig. 3082, and substituting in the general formula for the radius of curvature the values of the first and second differential coefficients, we find $r = -\dfrac{a\,(a^2 - y^2)^{\frac{1}{2}}}{y}$. Hence by geometrical construction the radius and centre of the osculating circle may be found thus;—let P Q be perpendicular to the tangent at P, and produced to meet a perpendicular to the directrix at T, the intercept P Q is the radius, and Q the centre of the osculating circle: for P M : P T :: T M : P Q, by the similar triangles M P T, R P Q.

To find the evolute of the Anti-friction Curve.—Let the co-ordinates of the centre of the osculating circle be x_1, y_1. By substituting in the general formulæ for the values of these the particular values of the differential coefficients, the results are $y_1 = \frac{a^2}{y}$ and $x_1 = x + \frac{a\,(y_1^2 - a^2)^{\frac{1}{2}}}{y_1}$. Eliminating x and y by means of these equations, and that of the curve, the result is $x_1 = a\,l.\left[\frac{y_1 + (y_1^2 - a^2)^{\frac{1}{2}}}{a}\right]$, which is the equation of the evolute. The evolute of the anti-friction curve of Schiele is therefore a catenary, whose parameter is a = A B, Fig. 3083, whose vertex is at B, and whose axis is A Y.

3083.



If a string P G applied to a catenary G B, have its extremity P at the vertex B, and be wound off, its extremity P will describe the anti-friction curve, in the examination of which mathematicians have blundered much.

FRICTIONAL GEARING. Fr., *Engrenage de frottement;* Ger., *Frictionscheiben;* Ital., *Ruote ad attrito;* Span., *Organo de trasmision de movimiento sin friccion.*

See Gearing.

FUEL. Fr., *Combustible;* Ger., *Brennmaterial;* Ital., *Combustibile;* Span., *Combustible.*

Great quantities of combustible substances, of immense importance in metallurgy and the various arts, are found in the bosom of the earth. They are evidently produced by the decomposition of vegetables which grew in the vicinity, or the *débris* of vegetables carried down by rivers. Peat mosses exhibit, though on a smaller scale, an example of this formation; as they consist of innumerable herbaceous vegetables, spontaneously decomposed by the action of water and atmospheric air; and their various stages of alteration may be followed, from the perfectly herbaceous turf to the earthy turf presenting but few or no recognizable remains.

The vegetable structure is frequently perfectly preserved in the mineral combustibles of the tertiary formation, where pieces of wood, called *lignite*, are found still retaining their original form, but having become friable, and yielding a brown powder by pulverization.

In the mineral fuel of older formations, the vegetable structure has generally disappeared, and it forms black, brilliant, compact masses, of a schistose texture, yielding a black, or more or less brown powder; it is called *pit-coal*, or *sea-coal*, and is rare in the secondary, but very abundant in the transition formation, in the upper stratum of which they are so frequent as to characterize them by the name of *coal formation*.

In the upper strata of the transition rocks the mineral fuel, which is sometimes called *anthracite*, is generally very compact, rich in carbon, difficult to ignite, and yielding but little volatile matter by calcination. Anthracite is sometimes, though rarely, found in the superior strata, and even in the secondary rocks.

Pit-coal of the coal formation yields on calcination a great quantity of volatile substances and inflammable gases, and experiences, prior to decomposition, an incipient fusion, while the coal remaining, or the *coke*, presents the appearance of a swollen or bloated mass. Although the structure of plants can no longer be recognized in certain combustible minerals, their vegetable origin is undoubted, for in the layers of schist or sandstone which bound the layers of coal, impressions of plants are frequently found, which are so distinct and clear as to enable the botanists to detect the family to which they belong, and thus, partly, to restore the flora of antediluvian epochs.

In the tertiary rocks a mineral fuel is also found, which is soft, or easily fusible, forming irregular masses, or a kind of strata, and presenting a bearing analogous to that of the lignites, while at other times they permeate layers of schist or sandstone belonging to various geological formations, and then seem to arise from the decomposition, by heat, of other combustible minerals contained in the earth. Some of these substances, which are called *bitumen*, contain a large amount of nitrogen, and are fetid, yielding, on distillation, considerable quantities of carbonate of ammonia. They appear to have been generated by the putrefaction of animal matter, chiefly by that of fishes, the impressions of which are frequently found in the neighbouring rocks.

Coals may be divided into five classes ;—

1. The anthracites.
2. *Fat and strong*, or *hard* pit-coal.
3. *Fat blacksmiths'* or *bituminous* coal.
4. *Fat* coal *burning with a long flame.*
5. *Dry* coal *burning with a long flame.*

1. Calcination scarcely changes the appearance of anthracites, as their fragments still retain their sharp edges, and do not adhere to each other. They have a vitreous lustre, and their surface is sometimes iridescent, while their powder is black or greyish black. They burn with difficulty, but generate a large amount of heat when their combustion is properly effected. In *blast furnaces* anthracites require a great blast, and those only can be used which do not soon fail to powder, as otherwise the furnace would be speedily choked. We find that anthracite is used in Wales for heating reverberatory furnaces; and it is now proper to remark, that the flame produced by the combustible under these circumstances is not owing to the combustion of the volatile substances given off by the anthracite, but rather to the combustion of the carbonic oxide formed by the passage of air through a thick layer of fuel.

2. Fat and strong, or hard pit-coals, yield a coke with metallic lustre, but less bloated and more dense than that of blacksmiths' coals. They are more esteemed in metallurgic operations requiring a lively and steady fire, and yield the best coke for blast furnaces. Their powder is brownish black.

3. Fat bituminous, or blacksmiths' coals, yield a very bloated or swollen coke, with metallic lustre, and are more highly valued for forging purposes, because they produce a very strong heat, and allow the formation of small cavities, in which the pieces to be forged can be heated. Blacksmiths' coal is of a beautiful black colour, and exhibits a characteristic fatty lustre: its powder is brown. It is generally brittle, and breaks into cubical fragments, which adhere to each other in the fire.

4. Fat coals burning with a long flame generally yield a swollen, metalloid coke, less bloated, however, than that of blacksmiths' coal. These coals are much esteemed in a reverberatory furnace, particularly when a sudden blast is required, as in puddling, and are also well adapted to domestic purposes, and are preferred for the manufacture of illuminating gas. They yield a good coke, but in small quantity, and their powder is brown.

5. Dry pit-coal burning with a long flame yields a solid, metalloidal coke, the various fragments of which scarcely adhere to each other by carbonization. This coal is also applicable to steam-boilers, and burns with a long flame, which however soon fails, and does not produce the same amount of heat as the coals of the preceding class.

The elementary analysis of combustible minerals, which easily explains their various properties, and indicates the uses to which each is most applicable, is effected like that of organic substances; but as coal is generally difficult to burn, it is necessary at the close of the experiment by which the quantity of water and carbonic acid it contains is determined, to pass a current of oxygen gas through a tube, which burns the last particles of carbon. The organic analysis of coal yields the hydrogen, carbon, and nitrogen which they contain; but it is also necessary to determine the proportion of earthy matter which exists in very various degrees in them, and which remains in the ashes after combustion.

For this purpose two grammes of the coal are ignited in a thin platinum capsule, heated by an alcoholic-lamp, and the ashes remaining are weighed. This method of incineration is difficult, and requires considerable time, only in those anthracites which do not burn readily, and it is then more easily effected if the coarsely-powdered anthracite be placed in a small platinum vessel, heated in a current of oxygen in a porcelain tube.

It is essential carefully to examine the nature of the ashes. Sea-coal of the coal formation frequently leaves argillaceous ashes, in which case there is a trifling error in the supposed composition of the fuel, because the small quantity of water always contained in clay, and which it loses at a red heat, is regarded as existing in the state of hydrogen; and this error, which is of no importance if the quantity of ashes is small, may be considerable in the opposite case. The ashes often contain, likewise, peroxide of iron, which metal generally exists in coal in the state of pyrites, and the analysis is thus inaccurate for two reasons: the proportion of ashes is valued at too low a rate, because, instead of the iron pyrites, sesquioxide of iron is weighed, the weight of which for the same quantity of iron, is less; and again, in combustion by oxide of copper, the substance may yield sulphurous acid, which interferes with the determination of hydrogen and carbon. The latter cause of error is avoided by placing in the combustion-tube, in front of the oxide of copper, a column of one or two decimètres of oxide of lead, which completely retains the sulphurous acid. The quantity of pyrites in the coal may be ascertained by determining, on the one hand, the quantity of sesquioxide of iron which exists in the ashes, and, on the other, the quantity of sulphuric acid yielded by a known weight of coal, powdered very finely, and acted on by fuming nitric acid, or ordinary nitric acid, to which small quantities of chlorate of potassa are gradually added. It is evident that these determinations are necessary only when the combustible produces a large quantity of ashes, and when the latter are very ochreous.

Coal belonging to the secondary and tertiary formations often yields calcareous ashes, in which case it becomes necessary, before weighing them, to sprinkle them with a solution of carbonate of ammonia, which is subsequently evaporated at a gentle temperature. But the determination of the carbon is generally inaccurate, because the carbonate of lime of the ashes gives off, by contact with the oxide of copper in the combustion-tube, a portion of its carbonic acid; and the oxide of copper must then be replaced by chromate of lead, intimately and largely mixed, with the coal reduced to impalpable powder, after which the carbonic acid produced by the carbonates of the ashes, which has been determined by direct weighing of these carbonates, is subtracted from the carbonic acid formed by combustion.

Coal also retains one or two per cent. of hygrometric water, which must be previously driven off by drying it in a stove at 270° or 280°.

It is necessary, in order to form a correct judgment of the nature of a combustible, to determine the weight of coke it yields by burning; and it is indispensable that this operation should always be conducted under the same circumstances, as the quantity and nature of the coke depend on the manner of calcination. The best method consists in placing 3 grammes of the coal in a thin platinum crucible, accurately covered by its lid, and rapidly heating to a red heat. The crucible is kept at a red heat for eight minutes, and after cooling without being uncovered, the coke is weighed and carefully examined.

The calorific power of fuel is calculated from its chemical composition; admitting that this power is equal to the sum of that of the carbon it contains, and that of the hydrogen obtained by subtracting from the total quantity of hydrogen that which would form water with the oxygen contained in the fuel. This hypothesis is not strictly true, but it may be admitted when the quantities of heat afforded by various kinds of fuel are only to be compared by approximation.

This comparison is generally made in another way, based on the supposition that the calorific powers of combustibles are in proportion to their reducing powers; that is, to the weight of the same oxide which they can reduce to the metallic state. An intimate mixture of 1 gramme of finely-powdered combustible and 40 grammes of litharge being introduced into an earthen crucible, 20 grammes of litharge are added, and the crucible is covered with its lid and rapidly heated to a red heat. It is allowed to cool, and, after being broken, the lump of lead is weighed, which rapidly separates from the scoria of the litharge; and it is assumed that the calorific powers of combustibles are in proportion to the weight of lead yielded by this experiment. This supposition is not absolutely exact, because combustibles yield, before attaining the temperature at which they act on the litharge, a small quantity of volatile substances possessing a reducing power—which substances are more abundant in combustibles of recent formation than in those containing a larger proportion of oxygen.

The following Table exhibits the composition of a large number of kinds of mineral fuel, taken from various geological formations, and from the kinds best marked and most extensively applied in the arts. The fragments containing least ashes have also been chosen, in order to cast no uncertainty on the composition of the combustible itself.

The Table contains, 1st, the actual composition of the coal, as afforded by direct analysis; and, 2ndly, the composition calculated by abstracting the ashes contained.

In order to see how the composition of mineral combustibles varies with their qualities in the arts and geological age, the numbers contained in the last three columns of the Table must be compared; that is, those which exhibit the composition of these combustibles after the ashes are removed. On assuming as a standard of comparison the coals of the third class, and ascending from this to those of the second, it will be found that the quantity of hydrogen is nearly the same, but that the oxygen has remarkably decreased and been replaced by carbon. On passing from the second class to the first, it will be observed that both the hydrogen and oxygen decrease, while the carbon increases in the same ratio.

Starting always from the *blacksmiths' coal*, we descend toward the fourth class, and remark that generally the hydrogen exists in greater quantity, and that the carbon decreases remarkably and is replaced by oxygen. Lastly, in the fifth class, the oxygen has still increased, and taken the place of a corresponding quantity of carbon.

Fat pit-coal may become dry in two ways: either by passing into anthracite, the hydrogen and oxygen both decreasing, and the carbon increasing in the same ratio, or by approaching the more modern combustibles, the *lignites*, the carbon decreasing and being replaced by oxygen; in which latter case the ratio between the oxygen and hydrogen increases.

By now comparing the combustibles of the secondary with those of the coal formation, it will be seen that, in the inferior stratum of the latter formation, the same variety can be distinguished. Thus, the anthracites of Lamure and Macot, which are found in the lower part of the Jurassic rocks, present the same composition as those in the transition rocks; while the coal from Obernkirchen, which also exists in the Jurassic formation, has the same properties and composition as those of the carboniferous formation. Lastly, the coal from Céral, which also occurs in the Jurassic formation, belongs, on account of its composition and applications in the arts, to the class of fat coal burning with a long flame.

The coal found in the upper stratum of secondary rocks resembles, on the contrary, the combustibles of the tertiary rocks or the lignites, which differ from the coal of the older rocks by containing less carbon and more oxygen; and as their formation approaches a modern period, their composition resembles more closely that of wood. The charcoal they yield by calcination becomes more and more dry: thus, the jet of chalk still yields a fritted metalloid coke, while the lignites of the tertiary rocks produce a non-metalloid charcoal, the fragments of which do not adhere to each other, and resemble in appearance wood-charcoal.

The bitumens, which are evidently products of distillation of older combustibles, or produced by the spontaneous decomposition of animal substances, differ essentially from coal properly so called, by containing much larger quantities of hydrogen.

See Assaying. Ballast, p. 218. Blast Furnace. Boiler. Brick-making Machine. Chimney. Coal Mining. Copper. Distilling Apparatus, p. 1218. Engines, Varieties of, p. 1418. Heat. Ventilating and Warming.

	Species of Combustible.	Locality.	Nature of the Coke, and other remarks.	Density.	Coke yielded by calcination.	Elementary Composition.				Composition, the Ashes being removed.		
						Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ashes.	Carbon.	Hydrogen.	Oxygen and Nitrogen.
TRANSITION ROCKS.	I. Anthracites	Pennsylvania	Is found in an argillaceous transition schist; fracture vitreous; coke pulverulent	1·462	89·5	89·21	2·43	3·69	4·67	93·59	2·55	3·86
		Wales	In the lower portion of the coal formation; fracture vitreous and conchoidal; coke pulverulent	1·348	91·3	91·29	3·33	4·80	1·58	92·76	3·38	3·86
		Mayenne	In argillaceous transition schist; fracture conchoidal and vitreous; coke not adherent	1·367	90·9	90·72	3·92	4·42	0·94	91·58	3·96	4·46
		Rolduc	Lower part of the coal formation; fracture vitreous, but texture laminated; coke slightly adherent	1·343	89·1	90·20	4·18	3·37	2·25	92·28	4·28	3·44
	II. Fat and hard pit-coal	Alais (Roche-Belle)	Coal sandstone; fracture unequal; coke metalloid; slightly swollen or bloated	1·322	77·7	88·05	4·85	5·69	1·41	89·31	4·92	5·77
		Rive-de-Gier (P. Henri)	Coal sandstone; fracture schistose; coke metalloid and swollen	1·315	76·3	86·65	4·99	5·49	2·96	89·29	5·05	5·66
	III. Fat blacksmiths' coal	Rive-de-Gier, 1	Coal formation; of a beautifully black greasy lustre; very swollen metalloid coke	1·298	68·5	86·25	5·14	6·83	1·78	87·82	5·23	6·95
		Idem, 2	Coal formation; of a beautiful black; fracture more schistose; coke rather less swollen	1·302	69·8	86·59	4·86	7·11	1·44	87·85	4·93	7·22
		Newcastle	Coal formation; of a beautiful black; fracture schistose and prismatic; coke swollen	1·280	..	86·75	5·24	6·61	1·40	87·97	5·31	6·72
	IV. Fat pit-coal burning with a long flame	Flénu of Mons, 1	Coal formation; rhomboidal fragments; coke swollen	1·276	69·8	83·51	5·29	9·10	2·10	85·30	5·40	9·30
		Idem, 2	Coal formation; less marked rhomboidal cleavage; coke swollen	1·292	..	82·72	5·42	8·18	3·68	85·88	5·63	8·49
		Rive-de-Gier (cemetery), 1	Coal formation; lustre feeble, texture schistose; coke swollen, but less brilliant	1·288	70·9	80·92	5·27	10·24	3·57	83·91	5·46	10·63
		Idem, 2	The same as No. 1	1·294	69·1	83·67	5·61	7·73	2·99	86·25	5·77	7·98
		Rive-de-Gier, Couzon, 1	Coal formation; lustre more marked, texture very schistose; coke swollen, but less brilliant	1·298	64·6	81·45	5·59	10·24	2·72	83·73	5·75	10·52
		Idem, 2	Coal formation; lustre very feeble; fracture unequal, and not schistose; coke less swollen	1·311	65·6	80·59	4·99	9·10	5·32	85·12	5·27	9·61
		Lavaysse	Coal formation; lustre brilliant; fracture conchoidal; coke swollen and light	1·284	57·9	81·00	5·27	8·60	5·13	85·38	5·56	9·06
		Lancashire	Coal formation; English *cannel coal;* without lustre; fracture conchoidal; coke fritted and brilliant	1·317	57·9	82·60	5·66	9·19	2·55	84·63	5·85	9·52
		Epinac	Coal formation; lustre brilliant, texture schistose; adherent metalloid coke, but slightly swollen	1·353	62·5	86·01	5·10	12·36	2·53	82·08	5·23	12·69
		Commentry	Coal formation; resembling cannel coal; fracture conchoidal; metalloid fritted coke	1·319	63·4	81·59	5·29	12·88	0·24	81·79	5·30	12·91
	V. Dry pit-coal burning with a long flame	Blanzy	Coal formation; fracture laminated; lustre brilliant; coke slightly adherent, but not swollen	1·362	57·0	75·43	5·23	17·06	2·28	77·19	5·35	17·46

	Species of Combustibles.	Locality.	Nature of the Coke, and other remarks.	Density.	Coke yielded by calcination.	Elementary Composition.				Composition, the Ashes being removed.		
						Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ashes.	Carbon.	Hydrogen.	Oxygen and Nitrogen.
SECONDARY ROCKS. Inferior stratum.	Anthracites ..	Lamure ..	Jurassic formation; greyish black; lustre vitreous; fracture conchoidal; coke pulverulent	1·362	89·5	88·54	1·67	5·22	4·57	92·78	1·75	5·47
	" ..	Macot.. ..	Jurassic formation; greyish black; lustre vitreous; coke pulverulent	1·919	88·9	70·51	0·92	2·10	26·47	95·90	1·25	2·85
	Pit-coal	Obernkirchen	Jurassic formation; aspect of fat coals; coke metalloid and swollen	1·279	77·8	88·27	4·83	5·90	1·00	89·16	4·88	5·96
	"	Céral	Marls of the lower oolite; aspect of coals burning with a long flame; coke metalloid and fritted	1·294	53·3	74·35	4·74	10·05	11·86	83·40	5·32	11·28
	"	Noroy	Variegated marls; of a dull black; fracture unequal; coke not adherent	1·410	51·2	62·41	4·35	14·04	19·20	77·25	5·38	17·57
SECONDARY ROCKS. Superior stratum.	Jet	Saint Girons	Green sandstone; very brilliant; fracture conchoidal; adherent metalloid coke	1·316	42·5	71·94	5·45	18·53	4·08	75·02	5·69	19·29
	"	Belestat ..	The same as that from Saint Girons	1·305	42·0	74·38	5·79	18·94	0·89	75·06	5·84	19·10
TERTIARY ROCKS.	I. Perfect lignites	Dax	Of a beautiful black; fracture unequal; free from ligneous texture; coke not adherent ..	1·272	49·1	69·52	5·59	19·90	4·99	73·18	5·88	21·14
		Bouches-du-Rhone ..	Schistose; pure and brilliant black; free from ligneous texture; coke not adherent	1·254	41·1	63·01	4·58	18·98	13·43	72·78	5·29	21·98
		Mt. Meissner	Brilliant; fracture conchoidal; coke feebly adherent	1·351	48·5	70·73	4·85	22·65	1·77	72·00	4·93	23·07
		Lower Alps	Black: lustre greasy; coke slightly swollen ..	1·276	49·5	69·05	5·20	22·74	3·01	71·20	5·36	23·44
	II. Imperfect lignites ..	Greece.. ..	Laminated; of a dull black; indices of vegetable organization; coke not adherent	1·185	38·9	60·36	5·00	25·62	9·02	66·36	5·49	28·15
		Cologne ..	Umber coloured; friable; streak reddish brown; texture ligneous; coke not adherent	1·100	36·1	63·42	4·98	27·11	5·49	66·04	5·27	28·69
		Usnach ..	Fossil wood; woody texture; very hard	1·167	..	55·27	5·70	36·84	2·19	56·50	5·83	37·67
	III. Lignites passing into bitumen ..	Ellebogen ..	Compact, homogeneous; fracture conchoidal; very light metalloid coke	1·157	27·4	72·78	7·46	14·80	4·96	76·58	7·85	15·57
		Cuba	Velvet black colour; lustre greasy; coke swollen and very light	1·197	39·0	74·82	7·25	13·99	8·94	77·88	7·55	14·57
	IV. Asphaltum	Mexico ..	Black; very brilliant; strong smell; melts below 212°; coke exceedingly swollen	1·063	9·0	78·10	9·30	9·80	2·80	80·34	9·57	10·09
Alluvial Formation.	Turfs or Peats	Vulcaire ..	In a very advanced stage of alteration, though still exhibiting some remains of vegetables ..	..	..	56·25	5·63	32·54	5·58	59·67	5·96	34·47
		Long	Similar to the foregoing	..	..	57·29	5·93	32·17	4·61	60·06	6·21	33·73
		Champ-du-Feu	In a less advanced stage of alteration, though still containing some vegetables	..	..	57·00	6·11	31·56	5·33	60·21	6·45	33·34
	Wood	.. ..	Average composition	..	..	49·60	5·80	42·56	2·04	50·62	5·94	43·44

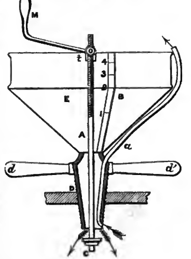
FULLER'S EARTH. Fr., *Argile smectique, Terre à foulon*; Ger., *Walkererde*; Ital., *Creta da sodare i panni.*

Fuller's Earth.—The fuller's-earth pits of Nutfield, near Reigate, are extensively worked, and supply large quantities of this substance to the clothing districts. There are two kinds, one greener than the other, owing to the presence of silicate of iron; but both exist under the same geological conditions, occurring in the lower cretaceous series, and differing little in chemical condition. Fuller's earth consists of about 45 silica, 20 alumina, and 25 water. When placed in water it almost dissolves, and when exposed to great heat it melts. It combines readily with grease, forming a kind of earthy soap, and for this reason is valuable in the manufacture of cloth made of animal fibre. The following is the mode of purifying and preparing the raw material for use;—The fuller's earth, after it comes from the pit, is baked or dried by exposure to the sun, and then thrown into cold water, where it falls into a powder, and the finer parts are separated from the coarser by a method of washing in several tubs, through which the water is conducted, and where it deposits the different kinds in succession. These are used for different kinds of cloth, the coarser part for the inferior, and the fine for the better kinds of cloth. The soapy combinations formed by fuller's earth with the greasy portions of cloth during the fulling of cloth, are supposed in some measure to serve the purpose of mordants.

FUNNEL. Fr., *Entonnoir, Évent, Hotte de cheminée*; Ger., *Trichter, Luftschacht, Rauchfang*; Ital., *Camino*; Span., *Chimenea.*

A funnel, possessing many advantages over those in ordinary use, invented by M. Bignon, is shown in Fig. 3084. Bignon's funnel is constructed of sheet iron. The merit of this apparatus consists in its being furnished at its lower extremity with a conically-shaped projection, which is, in fact, a screw, since it has a thread cut upon the whole of its length. The result of this arrangement is, that it will adapt itself indifferently to any sized bung-hole. At the bottom of this screw is placed a small clack-valve, which can be opened and shut as required. Fig. 3084 is a vertical section passing through the axis of the apparatus. The body E is of sheet iron, tinned inside and outside, and soldered to the upper part of the copper tube D, which has two little handles, $d\ d^1$, cast in one piece with itself, and which serve to screw and unscrew the funnel. As the tube hermetically closes the orifice of the cask, the air, which endeavours to escape from the interior, passes out through the little tube *a*, which has one extremity inside the screw-tube D, and the other outside the funnel. The lower extremity of the tube forms a seat for the valve *c*, which is attached to the central rod A, whose upper extremity passes through a socket *t*, which retains it in its proper place. The upper half of this rod has a thread cut upon it to receive the boss of the handle M, which acts upon it like a nut. The *modus operandi* is very simple and efficacious. On turning the handle M to the right or to the left, the opening or shutting of the valve *c* ensues, and the communication with the interior of the cask is thus opened or cut off, as required. There is a scale B attached to the interior of the funnel, which can be graduated to the measures of capacity in ordinary use, and which therefore registers the exact quantity of liquid poured into the cask. This is a very great advantage when it is necessary to complete the filling of a cask already partially filled, and saves the trouble of first ascertaining the quantity in the cask and then of calculating that necessary to fill the cask.

3084.



FURNACE. Fr., *Fourneau*; Ger., *Ofen*; Ital., *Forno*; Span., *Horno.*

Furnaces, or roast-ovens, are used for roasting ores; they differ greatly in their construction, according to the method of their use. Iron ores are roasted in ovens similar to a common *lime-kiln* of large size, and one that may serve for either roasting or burning *lime*. No fine or small ore can be roasted advantageously in an oven of this kind. For other ores than carbonates of iron, argillaceous ores, these kilns are not well adapted. Pyrites cannot be roasted in them, neither most other ores, because it is impossible to regulate the heat so as to prevent the melting of the ore; and if this happens, of course that ore is either lost or is with difficulty recovered. In roasting poor iron ores it is extremely difficult to regulate the fire so that no parts of the ore are burned dead or melted. For these reasons, kilns for roasting are not so much in use as would naturally be expected; they save fuel, but are more expensive in labour than the open heap.

Reverberatory Furnace.—This apparatus forms one of the best furnaces for roasting; but as its application is by no means general, and as the form of a roasting furnace is modified according to the kind, form, and uses of ore, we shall allude to this method when treating of those substances to which it is applied.

There is a variety of forms in the apparatuses for roasting, but we cannot perceive any advantage in the use of them; neither in the form of lime-kilns, for wood; nor cupola furnaces, constructed like porcelain kilns; nor large chambers, into which the flame from a grate is conducted through the ore; nor other forms of apparatus. These contrivances are not calculated for our smelt-works; they cause more labour, and absorb more capital, than a smelting business can afford.

Principles of Roasting.—Roasting means to heat a substance, a metal, or a metallic ore, or matt, to at least a red heat, or such a heat that the mineral does not melt, but only the volatile or combustible substances are expelled, and at the same time as much oxygen becomes combined with the ore as it possibly can absorb. It is therefore a principal condition, that with the heat a liberal quantity of atmospheric air, or oxygen, is admitted. In some cases chlorine, carbonic acid, carbon, or steam, is required along with the air, or in their pure conditions. In most instances, the object is merely to oxidize the ore to a higher degree, or to drive off volatile matter and in the meantime oxidize the ore, or to combine chlorine with a certain metal, as silver; or to reduce ore to metal, and evaporate the latter, which is the case with *arsenic*, *zinc*, and *antimony*.

The operation proceeds faster when the ore is fine than when it is coarse, because more surface is offered to the oxidizing agent; but this method includes the motion of the particles, so as to expose their various sides to the heat. It is not always necessary that the ore should be a fine powder; but it is of great advantage to have it in pieces of uniform size, because the action of heat and air is more regular, and the surfaces acted upon are larger. In roasting more or less fine powder, it should be stirred and moved while hot. The melting of the substance must by all means be prevented, for in that case neither evaporization nor oxidation can be accomplished. In the large operation, and in the reverberatory furnace, the melting of any kind of substance which is to be roasted is easily prevented. Roasting is always applied to oxidize iron ores, in order to obtain the highest degree of oxidation. A simple oxidation is performed when magnetic ores are exposed to heat and air, and transformed into peroxide. Chlorides are produced when, for instance, hot silver ore is brought in contact with chlorine, or a salt of chlorine, such as common salt; the roasting operation is here performed to reduce the oxide. When arsenic is to be evaporated, we put carbon in the mixture, and produce metal, which is more easily evaporated than its oxide. An evaporating, roasting process, is that which is performed on hydrated oxides, when only water is evaporated; a compound operation is performed when evaporation and oxidation are produced at the same time. In roasting pyrites, blende, and arseniurets, the volatile substances are driven off by heat, and the remaining metal is at the same time oxidized, which is brought, in most instances, to the highest degree of oxidation.

The affinity of the metals for other substances than oxygen, and the form in which these combinations appear, modify the process of roasting considerably. We shall allude to these particulars in the proper places; but it may be right to state here some general circumstances which have a bearing upon the subsequent operations. Iron cannot by any means be entirely freed from sulphur, phosphorus, or arsenic, by roasting; the presence of the vapours of water facilitates the expulsion of these substances, but the roasted ore never can be made entirely free from them. Blende, or sulphuret of zinc, is extremely slow to oxidize, and never can be purified from all the sulphur. Sulphuret of bismuth is equally slow of oxidation, not for want of affinity for oxygen, but because it is so highly fusible that its melting cannot be prevented. Sulphuret of copper is easily purified from all its sulphur. Galena is of very difficult oxidation, almost as much so as bismuth. Sulphuret of silver is easily liberated from its sulphur, and forms metal; the same is true with gold. Mercury acts in a similar manner, but it requires some caution to avoid evaporating the sulphuret of mercury with the sulphur. Sulphuret of antimony is of difficult oxidation, because it is extremely fusible. Sulphuret of arsenic is easily decomposed, but the result of the oxidation evaporates; the arsenious as well as the sulphurous acid both evaporate. The sulphurets of nickel and of cobalt are easily oxidized, and form pure oxides. Phosphorus and arsenic act in a similar manner as sulphur, and what applies to the latter applies to the former, with slight modifications. Phosphoric acid is more permanent than sulphurous acid, and silver cannot be entirely freed from arsenic if once combined with that substance.

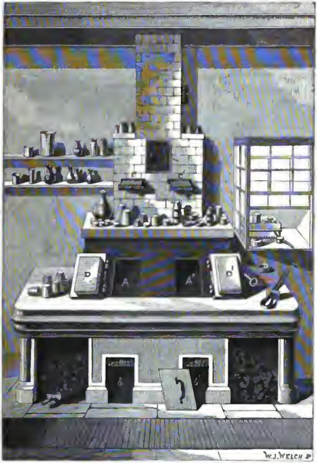
In quartz-crushing establishments generally, the assays of ores and tailings may be conveniently conducted in the furnace employed for retorting and melting, which is generally of sufficient size to admit of three or four fusions being carried on at the same time. In regular metallurgical laboratories, for the sake of durability, and to prevent the cracking of the brickwork, the outside of the melting furnace is usually secured by iron plates, as shown, Fig. 3085, which represents that employed by F. Claudet, and in which A A′ are the fire-places, B B′ the fire-bars, and *b b′* the ash-pits. The dampers C C′ permit of regulating the draught, and the mouths of the furnaces are closed by the hinged doors D D′, lined with baffle-plates. Instead of hinged doors, sliding plates are sometimes employed, and are, for general purposes, probably preferable. The dimensions of this furnace are, 10 in. square and 16 in. in depth above the fire-bars, which can, when necessary, be drawn out from the front for the purpose of allowing the coke to fall into the ash-pits *b b′*, or for unclinkering the grate. When used with charcoal, the crucibles must be supported on the bars on pieces of fire-brick; but when coke is employed, it has in itself sufficient resistance to allow of their being imbedded in the fuel without any other support.

The whole of the work lead produced at Pontgibaud is purified before it can be treated by Pattinson's process, and this is done by exposing it at a low red heat to partial oxidation in a *reverberatory furnace* specially adapted for that purpose. The chief impurity contained in the lead is antimony; the others are sulphur, iron, arsenic, and copper. All are in relatively small proportion, but are still in sufficient quantity to render the lead *hard*. The accompanying drawings, Figs. 3086 to 3088, show the arrangement and dimensions of the furnace employed.

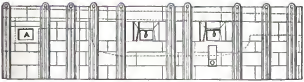
Fig 3086 is an elevation; Fig. 3087 a horizontal section at the level of the top of the pan; and Fig. 3088 a vertical section through the tap-hole. The fire-place A is separated from the pan B by a bridge 3 ft. 3 in. wide, and the furnace is provided with two doors *b*, through which the dross may be removed. In principle this resembles the ordinary softening furnace with its cast-iron pan, but its greater size and solidity of construction render it much more economical than the furnaces usually employed for the purpose.

On reference to the drawing it will be remarked that the pan is not only much larger than those

3085.



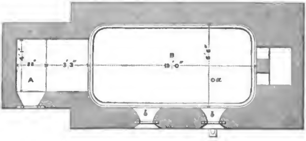
3086.



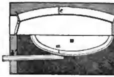
Improving Furnace.

commonly employed, but has also a rounded form; the object in giving it this shape being to diminish the tendency to crack, to which all square-sided pans are so liable. Another essential feature in the construction of these furnaces is to make them perfectly lead-tight, in case the iron should break. This is most effectually done by setting the pan on a bottom of well-beaten brasque 2 ft. in thickness, resting on a solid foundation of masonry. The sides of the furnace must be either of thick iron plates or of large cut stones. In either case the space between them and the pan should be at least a foot wide, and well filled with hard-beaten brasque.

3087.



3088.



The lead is tapped from the pan through a small hole *a*, ¾ of an inch in diameter, bored in the bottom of the pan, and communicating with a thick cast-iron tube *b′*, fastened to it by means of stud-bolts screwed into about half the thickness of the metal. Before charging, the hole in the bottom is plugged by a long pointed bar passed through an opening *c*, Fig. 3088, in the roof, corresponding with the tapping hole, and placed vertically over it. This bar will not generally stop the hole quite tight; especially after the furnace has been working a long time. The tube is, therefore, partly filled with bone-ash, firmly rammed in, a bar having been previously placed in the tube in such a way that the channel left, after its withdrawal, shall correspond with the hole in the pan. This horizontal bar is even more necessary than the vertical one; the use of the latter being to take off the pressure of the lead in the pan, and regulate the flow of metal in tapping. The horizontal bar is put in and withdrawn by the aid of a sledge; in much the same way as, though more easily than, a tapping bar at the blast furnace.

Both improving pans were originally lined with bricks, as shown in Figs. 3087, 3088, to protect the iron from corrosion by the oxides formed on the surface of the metallic bath. This precaution is now thought to be unnecessary; all that is required being to avoid overheating the furnace, and the consequent fusion of the dross. It is also found that a dull red heat is the best temperature for calcining Pontgibaud lead; and at that point the oxides neither melt nor exert any corrosive action on the pan, especially if a little lime be from time to time added. The usual charge of a pan without lining is about 20 tons. The brick lining diminishes its capacity by about one-fifth. A charge of 20 tons of common work lead requires sixty hours to become sufficiently soft for treatment by Pattinson's process, the whole time necessary for the operation, including charging and discharging, being three days.

Three men are employed in filling and emptying the pan, and are paid 2 francs each per charge. The pigs of lead are introduced through one of the working doors by means of a long charging bar, and the charging is effected with great ease and rapidity. Except for charging and discharging scarcely any labour is required, as the firing is attended to by one of the men working at the Castillian furnace.

An ordinary month's work at this furnace is as follows;—

Work Lead in. Tons.	Soft Lead out. Tons.	Percentage of soft Lead obtained.	Dross. Tons.	Coals consumed. Tons.	Lime used. Kilos.
139·150	131·528	94·7	8·675	11·560	554

The process of treating lead ores by metallic iron is chiefly employed for smelting galenas containing a considerable amount of silicious gangue. The reduction of galenas rich in lead, of which the matrix is chiefly calcareous, and which generally contain but a small amount of silver, is often effected by first roasting on the hearth of a *reverberatory* furnace, and a subsequent fusion in the same apparatus.

In this case the metal is obtained by the double decomposition which takes place between the undecomposed sulphide of lead and those portions of the ore which have, by roasting, been converted into oxide and sulphate of lead. In this way the decomposition of one equivalent of sulphide of lead, and two of the oxide of the same metal, give rise to the production of an equivalent of sulphurous acid, and the liberation of three equivalents of metallic lead,

$$PbS + 2\,PbO = SO^2 + 3\,Pb.$$

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In the same way, the fusion together of one atom of sulphide of lead and one of sulphate, results in the formation of two equivalents of sulphurous acid, and the liberation of two of metallic lead,

$$PbS + PbO, SO^3 = 2\,SO^2 + 2\,Pb.$$

The presence, however, of a very small proportion of silicious or argillaceous gangue renders the application of this principle extremely difficult, since when contained in the ores to the extent of only from 12 to 15 per cent., no metallic lead can be obtained in the reverberatory furnace by these reactions. As before stated, lead ores containing a large amount of silver cannot be advantageously enriched by mechanical treatment beyond a certain moderate percentage; and it is consequently usual, in smelting such minerals, to fuse them either in the raw state, or, after a partial roasting, with an admixture of metallic iron. The iron in this case, by combining with the sulphur of the galena, liberates the lead, and sulphide of iron is produced. When ores only partially roasted are operated on in this way, the intermediate reactions are of a somewhat more complicated character; but the final results, as far as regards the liberation of lead, are the same.

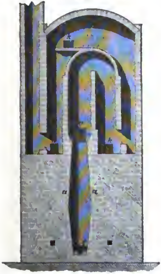
At Clausthal, in the Hartz, the ores usually contain about 30 oz. of silver a ton, and the furnace mixture consists of hand-selected and washed ores, to which are added certain secondary products, and a small proportion of granulated cast iron.

The charges are composed as follows:—

Hand-picked and washed ores, containing 55 per cent. of lead, 34 parts; old cupel bottoms, saturated with litharge, 4 to 6 parts; impure litharge from cupel, 1 part; slags from a previous fusion, or from the treatment of roasted matt, 39 parts; granulated cast iron, 4½ parts.

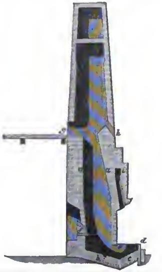
The fusion is conducted in a *blast* furnace, varying from 18 to 20 ft. in height, and having a width at the boshes of about 3 ft. 6 in., Figs. 3089 to 3091: Fig. 3089 being a vertical section at right angles to the tuyeres; Fig. 3090 a section through one of the nozzles; and Fig. 3091 a horizontal section above the breast-pan.

3089



Clausthal Furnace. Vertical Section.

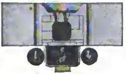
3090.



Clausthal Furnace. Vertical Section through Tuyere.

The casing walls are of common masonry, but the interior lining *a* is of fire-brick; the bottom *b* and breast-stone *c* are of sandstone, the breast-pan itself being supported by iron plates *d*. The brasque of which it is formed extends under the front wall of the furnace into the interior, and a communication is thus established by which the metal and liquid slags can flow into the pan *e*; the tuyeres *f* are placed in the back wall, and have a slight inclination downward, and also towards each other. At top, on a level with the charging hole, the form of this furnace is circular; at the level of the tuyeres it is a parallelogram, with truncated angles; and at the bottom, a square. The distance between the back and front walls is, at the tuyeres, 4 ft., and the width, 2 ft. 6 in. The diameter of the charging hole is 2 ft.

3091.



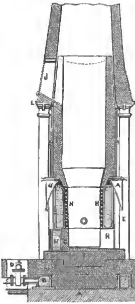
Clausthal Furnace.
Horizontal Section through Tuyeres.

This furnace is fed through the back by the opening *g*, and the small aperture *h* enables the workmen to instantly perceive the appearance of any flame which may escape at the top; it being essential, in order to avoid an undue waste of lead, to keep the charging hole constantly dead. The arrangement of the flues and condensing chambers is seen, Figs. 3089, 3090. The side flue *i* is connected with the projecting arch or mantle, and is for the purpose of carrying off any arsenical or other vapours that may arise from the breast-pan *e*. In the back wall of the furnace are small iron doors *k*, for the convenience of cleaning out the various deposit chambers and flues. On each side of the breast, on a level with the floor of the establishment, is a float or tapping pan *l*, into which the liquid metal is from time to time run out; whilst the slags flow off in a continuous stream from a notch in the iron plate supporting the brasque which forms the breast.

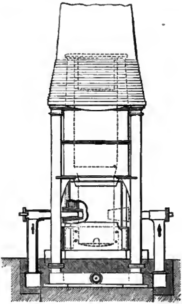
The ores are chiefly charged along the wall in which are placed the tuyeres, whilst the fuel is principally spread in the vicinity of that which is opposite to them. The blast, passing through the tuyeres, and coming into immediate contact with the liquid slags in the body of the furnace, so cools them as to form a tubular elongation or nose. This is so managed by the smelter as to extend from 5 to 6 in. beyond the tuyere. When the basin and hearth have become full of matt and metallic lead, a plug of clay is removed, and their contents are run off into one of the floats *l*, where they are allowed to remain until the matt begins to solidify, when it is removed in discs, as before described, and the metallic lead ladled into moulds ready for desilverization.

Thomas' Smelting Furnace, Figs. 3092 to 3094. The chief object of the inventor of this furnace is to construct air or blast furnaces which will the better withstand the action of heat and scouring fluxes in the melting of iron, copper, or other metals, or in the smelting of their ores. The main features of this invention, in addition to the general arrangement of the parts, are the construction of water-boshes, and the employment of spikes on the water-boshes. Fig. 3092 shows a sectional elevation; Fig. 3093 a similar view at right angles; and Fig. 3094 a sectional plan of one of these furnaces.

3092.

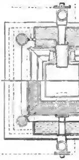


3093.



For a cupola or blast furnace John Thomas first makes a foundation A, and fixes therein a water-pipe B, which passes completely round the furnace, except at the front. There is a branch C to this pipe, to let the water in, the branch being provided with a valve and a valve-well D. There is also a branch at each corner of the pipe, upon which is fixed the hollow columns E E. These columns are closed at the top, and an entablature is fixed on them, on which the chimney is built. The water is let into the foundation-pipe B from a high level, so as to rise and fill the columns E E, the use of the columns being to hold water and carry the chimney. Brackets *a a* are cast on the columns to carry the plates O, which hold the upper brickwork of the furnace. Upon the foundation Mr. Thomas builds, as usual, up to the bottom of the furnace, as shown at F. He then places water-boshes M M, of cast or wrought iron, all round the furnace, except at the front, where there is a door R, as is usual in cupola furnaces, or a dam, as in blast furnaces. These boshes are set back 4½ in. from the face of the furnace inside, to allow of a thickness of lining G of fire-brick. He then places another tier of water-boshes N above those just described; these upper boshes go all round the furnace, or on all four sides. They have spikes *b b* cast all over their inner sides, similarly to iron-founders' loam-plates; these spikes may be of any suitable length, but 1½ in. is found to be sufficient for most purposes. The upper boshes against the spikes are lined with stiff mortar H H, made of refractory material, such as ganister and fire-clay, or road grit and fire-clay. On the brackets *a a* of the columns are placed the iron plates O O, which enclose the four sides. These plates reach nearly to the charging door J of the furnace. On the bottom edge of these plates there is a flange for carrying the brickwork I of the furnace, independently of the boshes N, so that if a bosh fails it can be taken out and another introduced without pulling down the brickwork.

3094.



The inside of the furnace is next built up from the top of the boshes with fire-brick, or other refractory material. The boshes M and N are filled with water drawn from the columns E E by a pipe connected with the bosh and the columns; each of these pipes has a tap to regulate the supply. A hole is cast through the side boshes for inserting the tuyeres *c c*; there are water-tuyeres also supplied from the columns E E, as shown in Fig. 3094. The inside of the furnace is similar in form to a blast furnace, larger at the upper part than at the bottom, and the crucible or lower part is made tapered. This form of furnace is best adapted to hold up the material under treatment, in order that it may be melted above the blast, and fall like rain-drops, and gravitate through the fluxes. If desirable, the lower boshes are spiked and brought forward to the face of the furnace, and lined against the spike, the same as the upper boshes. The principal novelty in this invention is the spiked boshes which hold up the lining, which cannot be fluxed away on account of the water in the boshes keeping the back of the lining comparatively cool. For air or reverberatory furnaces for smelting copper or other ores of metals, the bed of the furnace is built in the usual way up to within 4 in. or 6 in. of the bottom. The spiked water-boshes are then set around the sides and bridge of the furnace, and the spikes lined up against, as in the cupola or blast furnace. For a puddling furnace for puddling cast iron into wrought iron, the spiked water-boshes are set round the sides and bridge of the furnace, as in the copper-smelting furnace.

Brückner's Process for Chloridizing Silver Ore.—This process has been successfully introduced into the silver districts of Colorado, and a large percentage of all the silver produced in that territory during the last three years has been extracted by its use. The process has lately been so much improved that it offers decided advantages over the old plan of roasting and reverberatory furnaces. The expenses for labour and fuel are thereby very considerably reduced, and the roasting is done to a greater perfection and in a shorter time than in the reverberatory. One man can at a time attend to from six to eight of the furnaces by which the process is performed.

Brückner's furnace consists of a cylinder of boiler iron, lined in a durable way with strongly-braced brickwork, and made to revolve between a fire-box and a flue; from the fire-box the flame and air pass through a pipe into the cylinder, and from there, together with the gases produced in roasting, into the condensing chambers, from which the latter escapes through a smoke-stack.

A diaphragm made of cast-iron pipes is set at an angle of about 15° to the axis of revolution, and extends diagonally through nearly the whole length of the cylinder, for the purpose of moving the ore from end to end of the cylinder, thereby exposing it to the action of heat and atmospheric air in a very uniform manner, and performing mechanically the work of transferring the ore from the cooler parts, nearest to the flue, to the hotter, nearest to the fire-bridge, and *vice versâ*, which labour, by the old process, has to be performed by hand once every hour.

As the partition does not pass through the whole length of the cylinder, the latter is provided at each end with several flanges, set at an angle of about 45°, for the purpose of conveying the ore within the reach of the diaphragm.

The operation of the cylinder may be learned by any person in a few days, and is as follows;—A charge of 3000 lbs. of silver ore, and 150 to 300 lbs. of salt, is introduced through a man-hole into the cylinder, the inside of which has previously been heated to red heat, the opening closed, some more fuel thrown into the fire-box, and the cylinder made to revolve at one-half to one revolution a minute. The fire in the fire-box is so regulated that after one hour's time the sulphur contained in the ore commences to burn. Then the fire is so regulated that the ore is kept all the time at a dark red heat, gradually increasing to red heat. Very little fuel, and in ores containing much sulphur no fuel at all, is required until most of the sulphur has been oxidized; but then some more fuel is added in order to gradually increase the temperature of the ore pulp to an intense red heat. The pulp soon assumes a spongy, woolly consistency, in consequence of the mutual decomposition of the sulphates, formed in roasting, and salt, chloride of sodium, and of the chlorine gas being evolved; and after one hour's time, or as soon as a sample taken from the furnace evolves pure chlorine, and no sulphurous smell can be perceived any more, the chloridizing roasting is completed. Then the man-hole plate is removed, and while the cylinder is kept revolving the ore is made to drop through a grate into a screw conveyor, which conveys it through an iron trough kept cool from the outside by water. By this mechanical contrivance, the formerly so expensive, tedious, and unhealthy process of cooling the ore on a large cooling floor is done away with, and is performed to perfection, and without any additional labour, within fifteen minutes' time, since the ore by this process is by machinery directly carried into the screen and the hopper ready for further treatment.

Besides the last-named improvements, the inventor has also made some additional improvements for the purpose of increasing the working capacity of the cylinders, and to prevent at the same time all losses resulting from fine particles of ore and volatile chlorides from being carried off by the draught. It must be borne in mind that the greater the quantity of atmospheric air which comes into contact with the heated ore the quicker the roasting process is performed.

The arrangement consists in the use of a steam suction-pipe set, in the direction of the draught, into the flue between the cylinders and the condensing chambers; said pipe being arranged in such a manner that the draught through the furnace is considerably increased, and all volatile matter condensed and collected at the bottom of the chambers provided for this purpose.

This furnace can be used for roasting any kind of refractory silver ore; also for desulphurizing auriferous pyrites previous to chlorination or smelting; for roasting ores of zinc, lead, copper, &c.; also for burning cement, and for the manufacture of soda from cryolite.

The Stetefeldt Furnace.—This invention is one of the most important steps of progress yet achieved in silver metallurgy; and its direct effects in stimulating the production of bullion, by reducing its cost, will be felt immediately. Already the mines of many a half-abandoned district are augmented in value and importance by the mere announcement of its success.

The following description of the Stetefeldt furnace is from the notes of the inventor himself, and from the records of actual experience at Twin River, Reno, &c.

Since the discovery and exploration of the numberless mineral deposits in the Western States and Territories, no branch in metallurgy has received so much attention as the process of roasting ores of all descriptions. One can hardly look over a file of mining journals, or newspapers from some mining district, without finding descriptions of new devices for roasting ores, all of which claim to surpass everything else in this line which was known before. The devices are as strange as they are many, and much time and money have been wasted to test impracticable inventions. Indeed, the high expense which the roasting in the old reverberatory furnace entails was a strong inducement to invent some cheaper, and at the same time more effective, method. This is especially of importance where silver ores are found which require a chloridizing roasting preparatory to their amalgamation. In such cases the expense of roasting is frequently more than one-half of the total expense of reduction, and consequently low-grade ores cannot be worked with a profit. But in spite of the necessity to adopt some improved and more economical process of roasting, it has been extremely difficult to introduce two inventions, which are based upon the most simple and rational principles—so simple, indeed, that it seems impossible to simplify them any more. We refer to the Gerstenhöfer, or Terrace, furnace, first introduced about six years ago at Freiberg, and the Stetefeldt furnace, invented three years ago at Austin, Nevada, but first introduced for regular working at the mill of the Nevada Silver Mining Company, near Reno, Nevada. The nature of these inventions can be expressed as follows;—

Gerstenhöfer discovered that sulphurets are completely roasted or oxidized if they fall against a current of hot air rising in a shaft which is filled with shelves, so as to check and retard the fall of the ore particles at certain intervals.

Stetefeldt discovered that silver ores, no matter in what combination the silver occurs, mixed with salt are completely chloridized if they fall against a current of hot air rising in a shaft with no obstructions whatever to check or retard the fall of the ore particles.

It is a matter of course that in both cases a certain degree of fineness is required for the ore to be treated, and that a much coarser material can be successfully roasted in the Gerstenhöfer furnace than in Stetefeldt's.

In the Gerstenhöfer furnace only such ores can be successfully treated which, at a red heat during roasting, have no tendency to sinter or stick together. But the small particles of a charge of ore mixed with salt are exactly in such a condition while roasting as to have the greatest possible inclination to sinter and adhere to the shelves. They would thus soon obstruct the whole shaft, and prevent any further work. This has been demonstrated by actual experiments on a working scale. It is apparent, therefore, that the application of the Gerstenhöfer furnace, even for desulphurizing purposes, is very limited, and that certain classes of ore must be entirely excluded from it. This is especially the case with galena ores, which are the most expensive to roast in reverberatory furnaces.

In Stetefeldt's opinion, the shelves in the Gerstenhöfer furnace are perfectly superfluous, and all ores, even galena, can be desulphurized by dropping them through a plain shaft heated by fire-places below, if they are reduced to a sufficient degree of fineness. The escape of unroasted dust from the shaft is of no consequence, as a separate fire-place is constructed for the roasting of these suspended particles in the Stetefeldt furnace. Furthermore, the feeding machinery of the Stetefeldt furnace is based upon a principle entirely differing from that used with the Gerstenhöfer furnace.

That a furnace without shelves is cheaper and easier to construct, more durable, less liable to get out of order, and that it requires less labour and skill to run it, will be readily conceded.

Much difficulty was experienced to provide suitable feeding machinery for the Stetefeldt furnace. Gerstenhöfer's apparatus, consisting of fluted rollers, which force the ore through slits in the top of the furnace, would not answer at all. The ore fell down in lumps, and arrived at the bottom of the shaft almost raw. The reason for this behaviour is simply the tendency of the particles of all finely-pulverized mineral substances to adhere to each other if a slightly-compressed mass of them falls through the air. It is, therefore, necessary to introduce the ore pulp so finely divided, that all the particles can be penetrated by the heat within the short time of their fall through the shaft. To feed the pulp with a blower, as in Keith's desulphurizing furnace, was not considered desirable for the following reasons;—

1. The fall of the ore would be accelerated.

2. The draught of the fire-places would be impeded by the downward current of the air from the blower.

3. The formation of dust would be considerably increased.

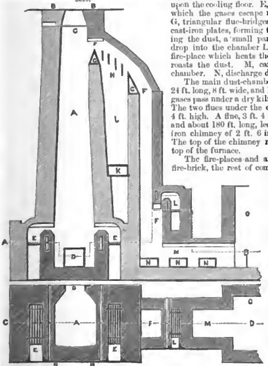
The feeding machinery in its present shape can be briefly described as follows;—

A hollow cast-iron frame, kept cool by a small stream of water, rests on top of the furnace. In this frame is inserted a cast-iron grate, which is covered by a punched screen of Russia iron, No. 0, for wet crushing of the trade. Close to the punched screen moves, inside of the hopper, a coarse wire screen, No. 3 of the trade, which is fastened to a frame. The frame has flanges resting upon adjustable friction rollers outside of the hopper, and receives its motion from a crank, with 1⅜-in. eccentricity. To avoid the motion of a stratum of pulp with the coarse screen, a number of thin iron blades are so arranged across the hopper that their lower edges reach close down to the coarse screen and keep the pulp in place. When the crank is set in motion, the meshes of the coarse wire screen cut through the pulp, and drive it through the openings of the punched screen. In this way the ore is introduced in a continuous stream into the furnace. The motion of the crank-shaft was variably tried in Reno at from thirty to seventy revolutions a minute.

Construction of the Furnace at Reno.—The accompanying drawing, Fig. 3095, will give a correct idea of the construction of the furnace at Reno;—

A, shaft through which the ore falls. B, top of shaft upon which the feeding machine is arranged. C, damper, which is inserted when the screens of the feeding machinery are exchanged. D, door through which the roasted ore is discharged upon the cooling floor. E, fire-place. F, flue through which the gases escape near the top of the shaft. G, triangular flue-bridges of cast iron. H, grate of cast-iron plates, forming the bottom of flue F, allowing the dust, a small part of which settles here, to drop into the chamber I. K, discharge door. L, fire-place which heats the lower part of flue F, and roasts the dust. M, canal connecting with dust-chamber. N, discharge door. O, dust-chamber.

3095.



The Stetefeldt Furnace.

The main dust-chamber of the furnace at Reno is 24 ft. long, 8 ft. wide, and 10 ft. high. From there the gases pass under a dry kiln, 39 ft. long and 7 ft. wide. The two flues under the dry kiln are 3 ft. wide and 4 ft. high. A flue, 3 ft. 4 in. wide and 4 ft. 6 in. high, and about 180 ft. long, leads from the dry kiln to an iron chimney of 2 ft. 6 in. diameter on a hill-side. The top of the chimney rises about 40 ft. above the top of the furnace.

The fire-places and arches are built of the best fire-brick, the rest of common brick. All the walls are built double, with a space between. The furnace is well anchored with iron rails and ½-in. rods.

The following changes are contemplated in the construction of the furnace;—

1. The use of oxide of carbon as fuel; the gas to be made out of charcoal in generators. The construction adopted for the latter will be similar to that of the copper-refining furnace at Mansfeld, Prussia. In this way a much more uniform heat can be obtained than by using wood, and labour will be saved, as the generators have to be charged only every three or four hours. Where wood must be hauled a considerable distance, charcoal will be even a cheaper fuel than wood.

2. The chamber I will be abandoned, and the flue F brought down directly on the side R R (see ground plan) of the shaft.

3. A more extensive system of dust-chambers will be connected with the furnace.

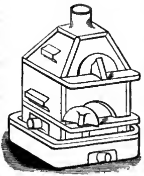
Manipulation.—The ore is mixed with the necessary amount of salt on the dry kiln, and crushed by a dry crushing battery through a No. 40 wire screen. A conveyor takes the pulp to a revolving screen, to keep out coarse particles, which may be caused by the breaking of a battery screen. The screened pulp is then taken by an elevator to the top of the furnace and discharged into a bin, which keeps the hopper of the feeding machine filled.

The fire is kept in all the fire-places as uniform as possible, and such a degree of heat is maintained that the roasted ore at the bottom of the shaft is red hot, but does not sinter or stick together. The ore is discharged when a charge of 1000 lbs. to a ton has accumulated, and cooled in the usual manner. At the same time, roasted ore is discharged through the door N, where most of the dust settles, which is roasted by the fire-place L.

Chemical Process in the Stetefeldt Furnace.—At the first glance it would seem that, considering the short time of two seconds, in which the falling ore is exposed to the flame, a perfect chlorination could not take place, especially if compared with the known facts apparent in the common roasting furnace—that is, that sulphurous acid is formed under influence of a dark red heat, by aid of the oxygen of the air, while the metal, deprived of its sulphur, becomes an oxide. The oxygen of the air and of the oxide act on the sulphurous acid, converting it into sulphuric acid, which again combines with the metal oxide to a sulphate. The sulphate reacts now on the salt, setting the chlorine free, and the formation of chlorides begins.

This reaction and transformation requires time, which is not offered in Stetefeldt's furnace, but the chlorination is effected nevertheless, and very perfectly, with less salt and in a few seconds. The chemical action in Stetefeldt's furnace is as follows:—As soon as the ore enters the furnace each sulphuret particle ignites, being surrounded by a glowing atmosphere, evolving at the same time sulphur, which, in presence of atmospheric air entering undecomposed through the grates, is converted into sulphurous acid, and the metal into an oxide. In contact with ore particles and oxygen the sulphurous acid becomes sulphuric acid. This acid does not combine with the metal oxide to a sulphate, as is the case in a common furnace; or if so, only to an insignificant degree, on account of the temperature, which, nearly from the start, is too high. The sulphuric acid, therefore, turns its force directly against the glowing salt particles, setting free the chlorine. All these reactions are, so to say, *in statu nascenti*. From the burning fuel steam is present among the gases, giving rise to the formation of hydrochloric acid. This hydrochloric acid not only originates directly by decomposition of the salt, but also from the chlorides of the base metals, which are formed in the upper part of the furnace, and again decomposed to oxides and hydrochloric acid in passing through the hot flame. The whole space of the furnace is then filled with glowing gases of chlorine, hydrochloric acid, sulphuric acid, sulphurous acid, oxygen, steam, and volatile base metal chlorides; all of them acting on the sulphurets and oxides with great energy. The chlorine decomposes the sulphurets directly, forming chloride of metal and chloride of sulphur. It decomposes and combines also with oxides and sulphates. The hydrochloric acid does the same. The sulphuric acid decomposes the salt and oxidizes the sulphurets, while the oxygen creates sulphurous and sulphuric acid and oxides. The red-hot ore falls down, and accumulating, continues evolving gases of chlorine, &c.

3096.



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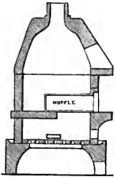
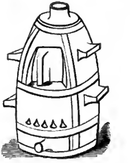


3098.



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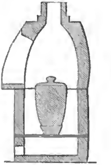


Considering now a minute particle of ore (for only as such, not as a mass, can the ore be considered in falling) in a red-hot state being attacked contemporaneously by all those gases which have free access from all sides; the principle of the Stetefeldt furnace is, that the chloridizing result must be effected before the particle reaches the floor. The dust which passes the flame of the small fireplace is even in a better condition for chlorination, being surrounded and acted upon longer by all the chloridizing gases which are formed in the main shaft.

Practical Results of the Stetefeldt Furnace in Chlorination.—A great number of tests were made during the first weeks of running the furnace at Reno. Between 88 and 92½ per cent. of the silver contained in the ore was found to be chloridized, all of which is easily extracted in amalgamation. The roasted dust discharged through the door N is generally 1 per cent. better chloridized than the ore discharged from the main shaft. With an improved system of firing, the chlorination should never be less than 90, and we have no doubt that much higher figures will be obtained. Only very skilled roasters achieve such results in the reverberatory furnace. With ordinary care, a charge cannot be burned in the Stetefeldt furnace, and the roasted pulp is in a splendid condition for barrel amalgamation, as it contains no lumps or sintered matter. Ores of the most various characters have been roasted with equal success. Even ore containing nothing but silver-bearing galena was treated without any difficulty. In this respect the furnace is admirably adapted to roast ores with large amounts of antimonial and lead-bearing minerals.

Amount of Salt.—In reverberatory furnaces 10 per cent. of salt is generally used. This amount may be safely reduced to 6 per cent. for very rich ores, and to 3 and 4 per cent. for low-grade ores, in the Stetefeldt furnace. No experiments have as yet been made to determine if this percentage can be reduced still more. The difference in the percentage necessary is explained by the fact that in the Stetefeldt furnace all the salt is decomposed and utilized, while in the reverberatory furnace a large percentage remains in lumps and entirely unchanged.

Fuel.—The amount of fuel necessary to heat the shaft depends very much upon the character of the ore. The more sulphurets an ore contains the less fuel is required to roast it. The furnace in Reno uses on an average about two cords in twenty-four hours. With this amount between 12 and 15 tons of ore are roasted daily, which is as much as the battery crushes. But the same fuel would just as well roast 20 tons of mainly sulphuret ores, which increase the heat in the shaft when introduced in larger quantities. How many bushels of charcoal a furnace with gas generators would require we are not able to estimate reliably at present; but for most localities in Nevada charcoal will be as cheap if not cheaper than wood.

Fig. 3098 is of a portable melting furnace; Fig. 3099 is section of 3098, which shows the interior arrangement and the position of the *crucible*.

This furnace, lately introduced by the Plumbago Crucible Company, Battersea Works, can be employed in a very confined space; no blower is necessary; its heat may be increased to melt gold by merely lengthening the funnel. This furnace is of great use to the gold-beater, as it renders him independent of the gold-refiner.

Figs. 3096 and 3097 are of a muffle furnace for assayers, dentists, and enamellers.

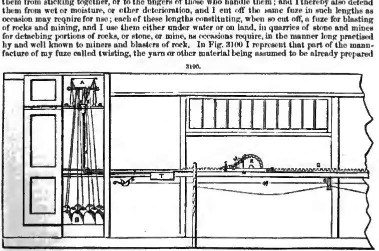
See ANEMOMETER. ANIMAL-CHARCOAL MACHINE. ASSAYING. BLAST FURNACE. BOILER, p. 466. CHIMNEY. ELECTRO-METALLURGY, p. 1374. FOUNDING AND CASTING. KILN. OVENS. See also articles on the various Metals.

FUZE. FR., *Fusée*; GER., *Zünder*; ITAL., *Fuso*; SPAN., *Espoleta*.

A *fuze* or *fuse* is a tube filled with combustible matter, and used for discharging shells, in blasting, and so on. See BORING AND BLASTING.

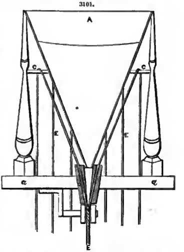
Fuze-making Machine, Bickford's, Figs. 3100 to 3105.—The fuze invented by Bickford for igniting gunpowder when used in the operation of blasting of rocks and in mining, which he called the miner's safety fuze, is manufactured by the aid of machinery, and of flax, hemp, or cotton, or any other suitable materials spun, twisted, and countered, and otherwise treated in the manner of twine-spinning and cord-making. Bickford, in describing his machinery, observes;—"I embrace in the centre of my fuze, in a continuous line throughout its whole length, a small portion or compressed cylinder, or rod of gunpowder, or other proper combustible matter prepared in the usual pyrotechnical manner of firework for the discharging of ordnance, and which fuze so prepared I afterwards more effectually secure and defend by a covering of strong twine made of similar material, and wound thereon, at nearly right angles to the former twist, by the operation which I call countering, hereinafter described, and I then immerse them in a bath of heated varnish, and add to them afterwards a coat of whiting, bran, or other suitable powdery substance, to prevent them from sticking together, or to the fingers of those who handle them; and I thereby also defend them from wet or moisture, or other deterioration, and I cut off the same fuze in such lengths as occasion may require for use; each of these lengths constituting, when so cut off, a fuze for blasting of rocks and mining, and I use them either under water or on land, in quarries of stone and mines for detaching portions of rocks, or stone, or mine, as occasions require, in the manner long practised by and well known to miners and blasters of rock. In Fig. 3100 I represent that part of the manufacture of my fuze called twisting, the yarn or other material being assumed to be already prepared and spun loosely, and wound into balls in the way commonly used and well known to manufacturers of twine and cord; and I also therein represent the mode of charging the fuze with the combustible.

3100.



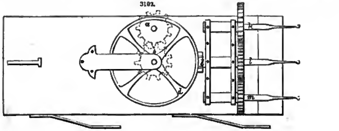
"At the left-hand end of an apartment, which is 65 ft. long, is made an enclosed recess or closet of about 2 ft. square and 6 ft. high, with a door or doors in front; in which closet, at the height of about 4 ft. 10 in., is placed a wooden shelf, marked A, about 1 in. thick at least, extending the whole length and breadth of such closet. In the centre of this shelf is made a hole, into which hole is inserted a collar, marked D. This collar is of metal, in form the frustum of a cone inverted. It is 3 in. long, 2 in. diameter at the upper end, and 1¼ in. at the bottom; through the centre of this is a hole, ⅜ of an inch diameter at the top, and $\frac{3}{16}$ of an inch diameter at the bottom. Around this, in a circle, are twelve holes, of about ⅛ of an inch diameter, which converge toward the centre hole at the bottom, so as to be separated by it only by a fine edge of the metal, Fig. 3101. D is a vertical section of the collar, and *r* the top and S the bottom of it. This collar, when so placed in the hole of the shelf, projects both above and below the wooden shelf. In the upper projecting part of the cone or collar is then to be placed a common funnel, 12 in. high and 10 in. in diameter at the top, as represented by the letter A; around this funnel, at about 10 in. high from the before-mentioned shelf, is placed a ring, made of cane, marked *c c*, and supported by a small frame of two or more pillars, resting on the before-mentioned shelf. At about 2 ft. 6 in. high from the floor of this room, and passing through the said closet, and extending the entire length of the said room 65 ft. long, is a stage or shelf or bench, marked F F; the outside of this stage or shelf or bench has a ledge or raised edge rising 1 in. above its surface, and on a similar raised edge on the inside, rising 1½ in., is a line-rack marked G G, with teeth or cogs, twenty teeth to a foot. This stage or shelf or bench is intended to support thereon a machine, being part of the apparatus thus used by me in my invention, called the monkey, marked H, which monkey consists, first, of a plane piece of board, 20 in. long and 6 in. wide, supported by and running upon three wheels of 1½ in. diameter; on this board, supported by and turning in two centres, is a transverse axle, marked 2, placed quite across the plane bed of the monkey, supported by brackets marked 1, 1, and turning round in holes made in the brackets, on the inside end of which is fixed a wheel marked K, of 10 in. diameter. Close to this wheel K, and directly over the line-rack, is placed on the said axle a pinion marked Z, which works on the cogs of the line-rack G G, on the side of which wheel K at its outer edge are twenty-four teeth or cogs; these teeth or cogs work into corresponding teeth on the inner circle of the wheel J, the wheel J having two circles of teeth or cogs, the inner and smaller circle working, as already described, in those of the wheel K, and the outer circle of cogs working into the pinion L; connected with this pinion L is the crook S, and to this crook the threads of twine or other material are attached for twisting. A string or cord M is fastened to the board of the monkey, and stretching along the stage or shelf or bench F F, passes over the pulley N, and returning through the holes O, O, O, made in the supports of the stage or shelf or bench, is attached to the winding roller P; in this situation of the apparatus twelve balls of twine marked B or other material intended to form the fuze are placed in the recess or closet on a floor raised there for that purpose 6 in. higher than the floor of the room, and the running threads from these balls are each led perpendicularly up through holes of 1 in. diameter, made for that purpose in a circle of 12 in. diameter in the shelf in which the before-mentioned collar is placed, and also perpendicular to and passed from the outside to the inside over the said cane ring next to the funnel hereinbefore mentioned, and from thence the said threads are again led down by the side of the funnel to and through the holes in the upper end under side of the aforesaid collar, which threads will then converge towards the lower point of the inner cone or collar, and there hang parallel and near to each other, and from thence they are to be led together to the pulley Q. Thence passing under the said pulley at a right angle they go to the monkey on the stage or shelf or bench, and are there made fast to the crook S. The winding roller P being now put in motion communicates that motion to the monkey H which travels on the stage or shelf or bench marked F F, towards N, and at the same time by the pinion marked Z working on the line-rack G G; the cog-wheels before mentioned marked J and K work the pinion marked L, and turning thereby the crook S, completely twist the twelve threads marked E so made fast thereto, and continue that twist up to the very point of the cone projecting downwards from the collar under the funnel; at the very same time of putting the monkey in motion the funnel is charged with the gunpowder or other combustible matter for making the fuze, and then it is important to carefully watch the progress of the threads, and prevent or rectify any entangling thereof; and also regulate the exit of the powder and prevent the dispersion of any surplus that falls to waste through the point of the cone or collar under the funnel during the operation of twisting. In this operation of twisting the powder passing the funnel lodges in the centre of the twelve threads, and is simultaneously embraced by all the threads, and the twisted part thus containing the powder is by the monkey drawn down and passes under the pulley Q, and continues its course with the monkey twisting the fuze along the stage or shelf or bench to the end of the room at N. Here the monkey stops, and this part of the fuze so charged

3101.

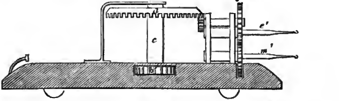


and twisted is then cut off, and over a box marked T placed on the said stage or shelf or bench to receive any gunpowder or other combustible matter used therein that may fall from the ends when so cut asunder; the two ends thus separated are secured by a knot or tie made on each; the part so twisted and separated is put aside for the subsequent operation of countering." By the monkey just described only one fuze could be spun at the same time, whereas it is desirable that several fuzes should be spun at once. By Bickford's improved machine, Figs. 3102 to 3105, three or more fuzes may be spun at the same time by one apparatus. The nature of this improvement, and the construction of the improved monkey for this purpose, will be seen by reference to the annexed figures. Fig. 3102 is a plane; Fig. 3103, a vertical longitudinal section; and Fig. 3104, a vertical transverse section of a monkey for spinning three fuzes at the same time. The wheel *a* works another of equal size and number of cogs *b*, shown in dotted lines in Fig. 3102, and seen in section in Fig. 3103. This wheel *b* has a vertical spill or centre *c*, Fig. 3103, on the upper part of which is a crown-wheel *d*, Figs. 3102, 3103, with teeth on its under edge working the pinion E, Figs. 3102, 3103, having on the outer part of its centre the cog-wheel *f*, Figs. 3103, 3104, with eighteen teeth working into the wheels *g*, *h*, *i*, Fig. 3104, of the same size and number of teeth; on the centres of the wheels *g*, *h*, *i*, are the wires and crooks *k*, *l*, *m*, Fig. 3102. To these crooks are attached the several yarns, which as the monkey travels along the bench are spun into fuzes. We prefer to have fifty-two teeth in the crown-wheel *d*, eight teeth in the pinion *e*, twelve teeth in each of the wheels *a* and *b*, and twenty-four teeth to a foot in the side rack. In order to use this improved monkey it is necessary to increase the number of funnels for the gunpowder and collars, which may be arranged as shown in Figs. 3105, 3106. Fig. 3105 is a plan of these collars cast in one united piece of brass-work, *k*, *l*, *m*, being the three several collars, the whole being fixed to an upright frame by the screws D, E; the centre holes *n*, *o*, *p*, being intended for the reception of the gunpowder funnels *w*, *x*, *y*, Fig. 3106, and the several circles of holes *q*, *r*, *s*, being intended to receive the yarns, which meet below and embrace the gunpowder as the fuze is spun. Fig. 3106 is a vertical view of this same part of the machine. *k*, *l*, *m*, are the three collars; *t*, *u*, *v*, are the yarns passing into the several

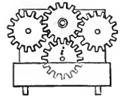
3102.



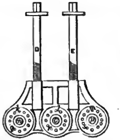
3103.



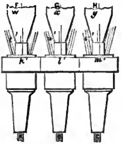
3104.



3105.



3106.



circles of holes around the mouth of the funnel; *w*, *x*, *y*, are the three gunpowder funnels, and A, B, and C, the three fuzes issuing from the interior tube beneath. By placing the wheel *f*, Fig. 3103, in such a position that a large number of wheels may work into its teeth, and making such other necessary additions and arrangements as will be obvious to any competent workman, four, five, or more fuzes may be spun at one single operation.

Our second improvement in manufacturing fuzes relates to the mode of introducing the gunpowder according to the method described in the said specification; the gunpowder is not supplied from the funnel with the rapidity, regularity, and certainty which may be attained by our improvement. We introduce into the centre of the fuze a small strong thread or yarn, smaller and less fibrous than the yarns employed for the fuze. The thread or yarn which we employ is that known as No. 135 white-brown thread; this we supply from a reel or other source conveniently placed above the funnel containing the gunpowder; this thread or yarn is passed down through the gunpowder and spun into the centre of the fuze by being attached to the monkey and drawn on with it as the fuze is spun. The position of these threads is shown by F, G, H, Fig. 3106. By means of this thread so drawn on as the fuze is spun the gunpowder in the lower part of the funnel is constantly kept in motion and travels on with the thread, so as to flow regularly down into the fuze. By this means the continuity and regularity of the cylinder of gunpowder is ensured.

Our third improvement relates to the coating or varnishing applied to those fuzes which are to be used for blasting in dry ground, and in close or confined situations, or which are subject to considerable variations in temperature. The coating or varnishing heretofore applied, consisting of tar or resin, burns with a great deal of smoke and heat, and is affected by changes of temperature. Instead of a coating or varnish of either of those materials, we take 4 lbs. of best glue and 2 lbs. of yellow soap, and having dissolved them in 12 gallons of water by a gentle heat, we add 56 lbs. of whiting to give it a body; the varnish so made is applied to the fuzes by any suitable arrangements. The new varnish, not being waterproof, must not be employed for fuzes which are to be immersed in water, but being less affected by temperature than the old varnish, and being non-inflammable or burning with little smoke, is much preferable for general purposes.

Our fourth and last improvement relates to fuzes which are to be employed under water. In the manufacture of fuzes to be employed under water, or waterproof fuzes as they are called, it has been usual to add a second countering, after which the fuze was coated or varnished a second time in the usual manner. But fuzes prepared in this manner occasionally failed, in consequence of the varnish becoming more hard and brittle on immersion in water and cracking, and thus admitting the water to the gunpowder. Our improvement for obviating this defect is as follows;—After the fuze has been coated or varnished with tar or resin varnish, and before the coating is hard or quite set, the fuze is fastened to crooks and made to revolve as if for countering, and a strip of brown paper is wound around the fuze in a spiral form, so as completely to envelop and cover the whole surface of the fuze. A thread is then wound round over the paper, which fixes the paper and prevents its shifting; another coat of tar or resin varnish is then applied to the paper, and by this means the fuze may be completely waterproofed and protected against the action of the water.

FUZEE. FR., *Fusée*; GER., *Schnecke*; ITAL., *Piramide*; SPAN., *Rueda espiral.*

See ESCAPEMENT. WATCH AND CLOCK MAKING.

GABION. FR., *Gabion*; GER., *Schanzkorb*; ITAL., *Gabbione*; SPAN., *Gavion, ceston.*

See FORTIFICATION.

GAD. FR., *Pointerolle, Aiguille du mineur*; GER., *Setzeisen, Stufeisen*; ITAL., *Zeppa*; SPAN., *Cuña de acero.*

A *gad* is a wedge of steel for driving into crevices or openings made by the pick or chisel.

GALVANISM. FR., *Galvanisme*; GER., *Galvanismus*; ITAL., *Galvanismo*; SPAN., *Galvanismo.*

See BATTERY. TELEGRAPHY.

GALVANIZED IRON. FR., *Fer zingué*; GER., *Galvanisirtes Eisen*; ITAL., *Ferro zincato*; SPAN., *Hierro galvanizado.*

See ZINC.

GAS. FR., *Gaz*; GER., *Gas*; ITAL., *Gas*; SPAN., *Gas.*

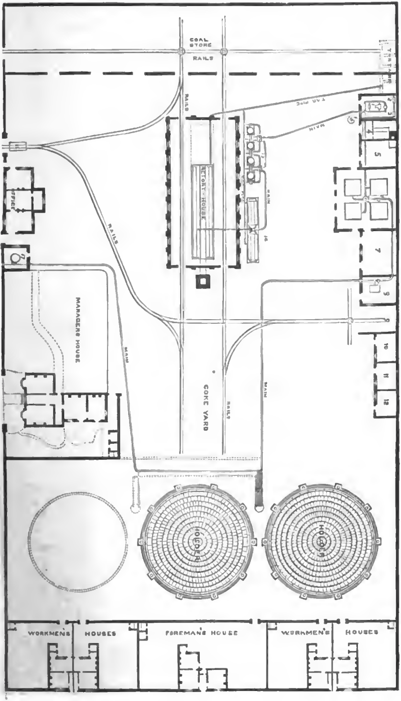
The common gas used for illuminating purposes is a mixture of carburetted hydrogen and olefiant gas, or bi-carburetted hydrogen, which gives a brilliant light when burned.

GAS, MANUFACTURE OF. FR., *Fabrication du gaz*; GER., *Gasbereitung*; ITAL., *Fabbricazione del gas*; SPAN., *Fabricacion de gas.*

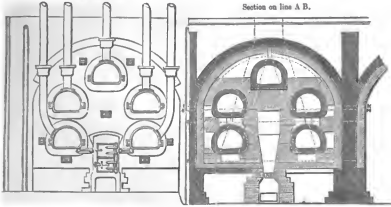
Fig. 3107 is a general plan of a gas-works by Geo. Bower, of St. Neots, Hunts. 1, is the exhauster; 2, the tar-pump; 3, water-pump; 4, boiler; 5, fitters' shop; 6, purifier house; 7, lime-stores; 8, meter; 9, spent lime; 10, 11, and 12, stores; 13, scrubbers; 14, condenser; 15, weigh-bridge; 16, water-well; 17, governor. It is very complete, and with the aid of the details shown on a larger scale in the following figures will illustrate the most modern and approved practice.

Figs. 3107 to 3113 represent sections and part elevations of the retort setting. The retorts are of *fire-clay*, provided with cast-iron mouth-pieces, from which ascension pipes conduct the gas produced in the retorts to the hydraulic main shown in the general plan, Fig. 3107. The retorts are heated in beds of five each, by means of a small furnace, under the fire-bars of which is placed a cast-iron evaporating cistern or pan, into which the ashes from the furnace are allowed to fall, and which evaporate either waste or ammoniacal liquor. The charge for each retort is about 1½ cwt. of coal, drawn at the end of each six hours, producing at the heat of 27°, Wedgwood's *pyrometer*, about 700 cub. ft. of gas, or 3500 cub. ft. in the six hours, for each single bench of five retorts. The retorts are set in double benches end to end, and are charged from both sides of the house. A tramway is provided in front of the benches, connected with the coal-shed and the general system of rails on the works, so that the coal may be taken to, and the coke from the retorts with great facility.

The hydraulic main consists of a horizontal pipe laid above the retort benches supported on small pillars. Into the main the whole of the pipes from the retorts are made to dip. The main

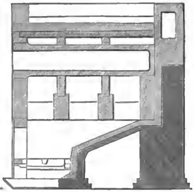

COAL STORE
RAILS
TAR TANK
TAR PIPE
MAIN
RETORT HOUSE
OFFICE
MANAGERS HOUSE
COKE YARD
HOLDER
HOLDER
WORKMEN'S HOUSES
FOREMANS HOUSE
WORKMEN'S HOUSES
1
2
3
4
5
7
9
10
11
12
14
17

3107.

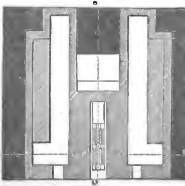

3108.

Front Elevation.

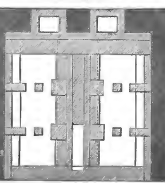
Section on line A B.


3109.

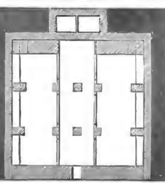
Section on line C D.


PLAN ON LINE E.F

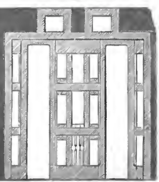
3110.


PLAN ON LINE. H.G

3111.


PLAN ON LINE.I.K

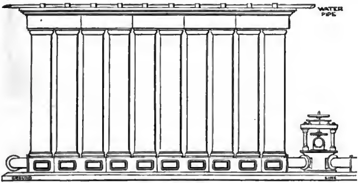
3112.


PLAN ON LINE. L.M

3113.

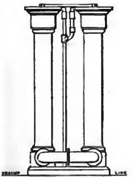
is kept about half filled with tar, and the dip-pipes are made to terminate about 1½ in. below its level; a sealed liquid joint is thus made, which prevents the return of gas to the retorts when the lids are removed. A considerable quantity of tar is formed in the hydraulic main from a partial condensation of the gas as it passes from the retorts on its way to the condenser shown at 14 on the plan, Fig. 3106. To prevent a too great deposit of tar in the hydraulic main an overflow pipe is inserted at one end, so that the tar is maintained at one universal level, and the surplus is conducted through the tar-pipe to the dip which leads to the tar-cistern. The condensers are formed of vertical columns with internal pipes, in which water circulates for the more effectual cooling of the gas. The internal pipes are kept filled with water, and circulation is kept up by making a small supply-pipe to terminate near the bottom of the column inside. The construction is clearly shown in Figs. 3114 to 3117. *a* is the condensing column; *b*, the water column; *c*, the water-

3115.



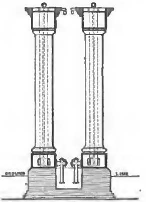
Front Elevation.

3114.



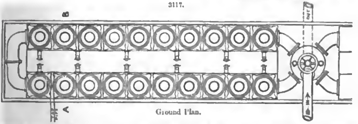
End Elevation.

3116.



Section on line A B.

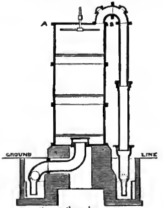
3117.



Ground Plan.

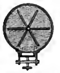
supply pipe; *d*, the tar-dip; and *e* the dip-pipes, through which the tar is conveyed from the condensers as it is formed. The tar-dip is prevented from overflowing by means of a tar-pipe shown on the general plan. The tar-pipe is laid behind the condensers and scrubbers, with branches from each of the tar-dip cisterns, and is connected with the tar-pipe from the hydraulic main, so that all the tar and ammoniacal liquor formed on the main, the condensers, and the scrubbers, is conveyed as it is formed to the tar-tank. There are four condensers arranged so that by means of the centre

3118.



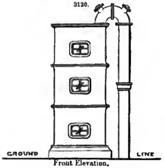
Section through centre.

3119.



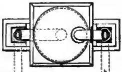
Section on line A B.

3120.



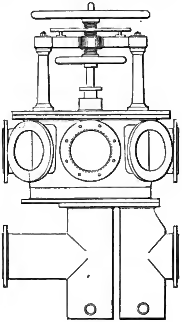
Front Elevation.

3121.



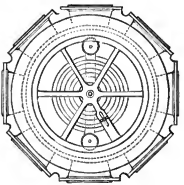
Plan.

3123.



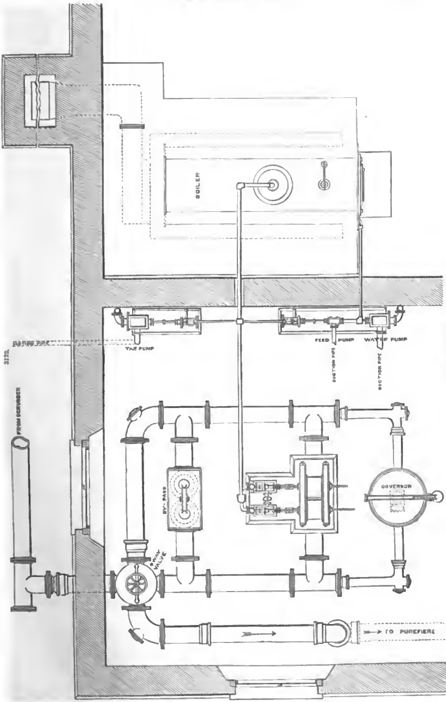
Elevation.

3124.



Plan.

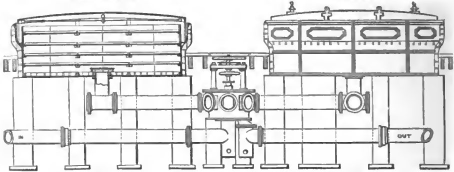
3132.



Exhausting Apparatus.

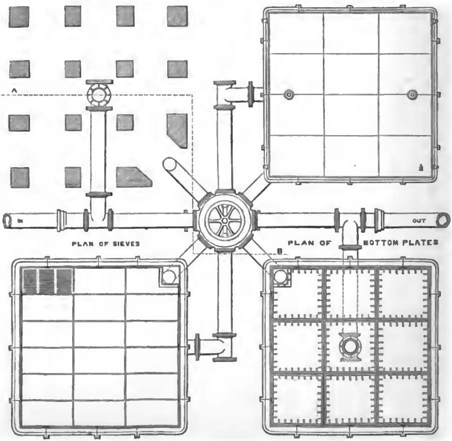
3125.
Section on line A B.

3126.
Elevation.



3127.
PLAN OF FOUNDATIONS

3128.
PLAN OF LID

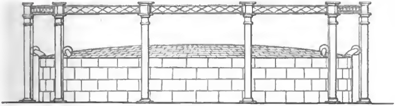


3129.

3130.

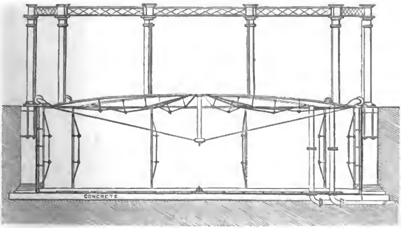
valve (14 on plan) either pan may be worked without the other, or both may be worked together. After passing the condensers the gas is conveyed to the scrubbers. The scrubber is for the purpose of more effectually cleansing the gas from ammonia than can be effected in the condenser. The construction of the scrubber will be seen from an inspection of Figs. 3118 to 3121. The gas enters the bottom of the scrubber and passes up through three tiers of sieves, which are filled to a considerable depth with coke or other material presenting large scrubbing surface, which is kept saturated with water or ammoniacal liquor by means of a rose or water spreader, consisting of small radiating pipes perforated with holes. The great amount of surface exposed to gas in passing by the wet scrubbing material collects the fatty oils, absorbs ammonia, and cleanses the gas mechanically before entering the purifiers. There are four scrubbers (shown at 13 on the general plan, Fig. 3106), provided with four valves, by means of which each or either of them may be thrown out of action to provide for the renewal of the scrubbing material. From the scrubbers the gas passes on to the exhausting apparatus. The use of the exhauster is to relieve the retorts from internal pressure during the production of gas; by which the yield of gas is increased from 6 to 10 per cent. The pressure of gas in the retorts, were it not for the exhauster, would be equal to that required to lift the gas-holder and overcome all other resistances on its passage to that vessel; the exhauster pumps the gas as fast as it is made, and thus maintains the pressure of the gas-holder on the delivery side of the pump. The construction of the exhauster is shown in Fig. 3122. It consists of a pair of direct-acting pumping engines, with horizontal pumps placed on a strong cast-iron bed-plate. The engines and pumps are exceedingly simple; there is no fly-wheel or crank, but the piston-rod of the steam-piston is attached directly to the pump-piston, and by means of a peculiar valve-gear the reciprocations of the pistons are produced; the two pumps can be worked together or separately as desired. At the corner of the exhauster house is placed a four-way valve, by means of which the gas may be made to pass on to the purifiers and so throw the exhauster out of use if desired; at one end of the exhauster is placed a by-pass valve, which allows the gas to pass in event of the exhauster ceasing to work from accident or other cause; at the other end is placed a governor, which allows some of the gas to pass back again should the exhauster be pumping too fast for the production of the retorts. This arrangement renders the whole of the apparatus self-acting, requiring no skilled attention. The feed-pumps for supplying the boiler and the tar and water pumps are constructed in a similar manner to that of the exhauster, and being complete

3131.



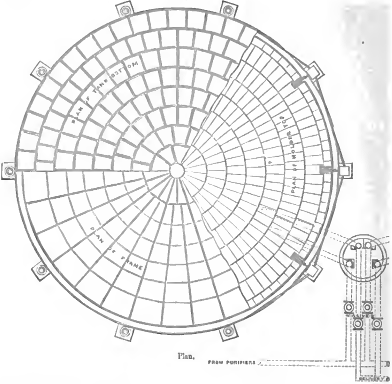
Elevation.

3132.



Section.

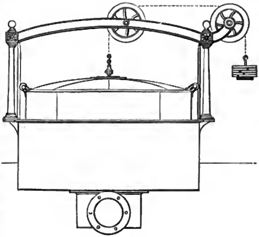
3133.



Plan.

in themselves, an accident with one does not interfere with the others. After passing the exhauster the gas enters the purifiers through a centre valve shown at 6 on the plan. The centre valve, Figs. 3123, 3124, is what is called a dry one, and so constructed that three purifiers may be at work and one out for renewing with lime, or any combination can be made, such as one in and three out or two in and two out, all the changes being made with one valve. The purifiers are clearly represented in Figs. 3125 to 3130, as is also the centre valve and connections. The purifiers are for dry lime, with four tiers of sieves, each carried on angle-iron, as shown in Figs. 3125 and 3129. The sieves are made of wood in square frames, as shown on the plan. Each purifier is supported on brick piers, which are represented in Figs. 3125 to 3127. The gas is made to enter the purifiers, and after

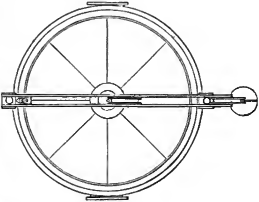
3134.



Elevation.

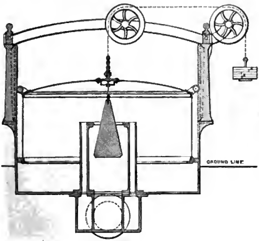
passing through the lime spread over the surface of the sieves, makes its exit through the corner pocket *d*. After passing the purifiers the gas has only to pass through the station meter before being conducted to the gas-holder. The station meter is made to register the gas produced, and by working in connection with a clock, shows the relative quantities produced at each hour of the day. The gas-holders, Figs. 3131 to 3133, are each 80 ft. diameter; a dry well is made by the side of each, through which the inlet and outlet pipes are laid; each pipe is made to dip in a box at the bottom of the well, from which the water formed in the pipes is pumped out by means of a hand-pump. The well *c*, Fig. 3106, answers for the two holders, and the other well *f* is a reserve for the third holder when erected. A stop-valve is placed to each of the inlet and outlet pipes. On the outlet pipe (17 on plan) is fixed the *governor*, Figs. 3134 to 3137, which governs the pressure at which the gas is supplied to the town. It is of great importance to the engineer that the pressure of gas should be preserved constant at various points on the works; and that he may be enabled to ascertain the pressure at any given point, pressure gauges are placed in various situations: the most important gauges are those placed one before and one after the governor. The former shows the pressure given by the gas-holder, and the latter the pressure at which the gas is delivered into the town. There is also a gauge placed at each of the condensers and scrubbers, one on the suction and one on the delivery side of the exhauster, and one near the purifiers. In the block of the office is provided a room for photometric observations. The general plan shows the arrangement of a works capable of supplying a town requiring about 10,000 lights burning for five hours out of each twenty-four; or it would supply 2000 public lamps burning twelve hours, and 6000 private lights burning four hours per twenty-four; or equal to the wants of an English town of 50,000 or a Continental town of 100,000 inhabitants.

3135.



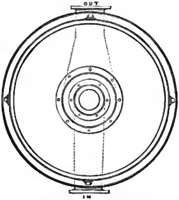
Top Plan.

3136.



Vertical Section.

3137.



Section through Tank, showing Valve, Seat, and Outlet.

Works relating to Gas:—T. S. Peckston, 'A Treatise on Gas Lighting,' 8vo, 1841. S. Hughes, 'A Treatise on Gas Works,' 12mo, cloth, 1866. W. R. Bowditch, 'The Analysis, Technical

Valuation, Purification, and Use of Coal-Gas,' 8vo, 1867. N. N. Schilling, 'Traité d'Éclairage par le Gaz,' traduit de l'Allemand par E. Servier, 4to, Paris, 1868. S. Clegg, jun., 'A Practical Treatise on the Manufacture and Distribution of Coal-Gas,' 4to, 1868. T. Newbigging, 'The Gas Manager's Handbook,' 8vo, 1870. 'The Journal of Gas Lighting,' small folio, 1849 to 1870. 'Annual Reports of the Trustees of the Philadelphia Gas Works,' 8vo, various years. 'Reports of the Proceedings of the British Association of Gas Engineers,' 8vo, various years.

GAS-HOLDER. Fr., *Gazomètre*; Ger., *Gasometer*; Ital., *Gasometro*; Span., *Gasómetro*.

See Gas.

GAS-METER. Fr., *Compteur au gaz*; Ger., *Gasmesser*; Ital., *Misuratore del gas*; Span., *Contador de gas*.

See Meter.

GASOMETER. Fr., *Gazomètre*; Ger., *Gasometer*; Ital., *Gasometro*; Span., *Gasómetro*.

See Gas.

GATES. Fr., *Porte*; Ger., *Thor*; Ital., *Porte*; Span., *Puertas*.

See Docks. Locks and Lock-gates.

GAUGE. Fr., *Tauge*, *Échantillon*; Ger., *Urmass*, *Aichmass*.

A *gauge* is a measure; a standard of measure; an instrument to determine dimensions or capacity; a standard of eny kind. In mechanics and manufactures;—any instrument for ascertaining or regulating the dimensions or forms of particular things, as a *button-maker's gauge*, a *gunsmith's gauge*, or a *template*. The distance between the rails of a railway. When the railway-gauge is 4 ft. 8½ in., it is called narrow gauge; wide or broad gauge in England is 7 ft., in the United States 6 ft. There are also other intermediate gauges. In plastering, the greater or less of plaster of Paris used with common plaster to accelerate its setting; or the composition made of plaster of Paris and other materials used in finishing plastered ceilings for mouldings, and the like. The *gauge of a carriage* is the distance between the opposite wheels when on the track. *Joiner's gauge*, an instrument used to strike a line parallel to the edge of a board, &c. *Printer's gauge*, an instrument to regulate the margin of the page. *Rain-gauge*, an instrument for measuring the quantity of rain at any given place. *Salt-gauge*, or *salinometer*, a contrivance for indicating the degree of saltness of water from its specific gravity, as in the boilers of ocean steamers. *Standard gauges*, templates, and patterns of certain parts, and tools common to all machine work. *Steam-gauge*, an instrument for measuring the pressure of steam in a boiler. *Tide-gauge*, an instrument for determining the height of the tides. *Vacuum-gauge*, a species of barometer for determining the relative elasticities of the vapour in the condenser of a steam-engine and the air, or for indicating the difference between the vacuum of a condenser and a perfect vacuum. *Water-gauge*, a contrivance for indicating the depth of water as in a steam-boiler, as by a gauge-glass or cock. The term *water-gauge* is also applied to the height of water in a boiler, as three *gauges of water*, that is water up to the third cock. See Anemometer. Details of Engines. Dynamometer. Fan. Meters. Vacuum-gauge.

Birmingham Wire Gauge, Fig. 3138.

3138.

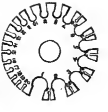
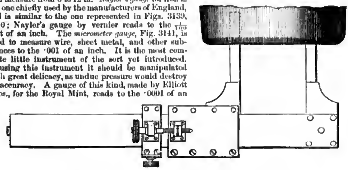


Table of the Birmingham Wire Gauge, by Sabine and Clark.

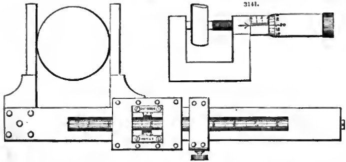
No. B. W. G.	d = diam. in inches.	d^2.	Sect. area in square inches.	No. B. W. G.	d = diam. in inches.	d^2.	Sect. area in square inches.
1 circ. in.	1·000	1·0000	·7854	13½	·089	·0079	·00622
0000	·454	·2061	·16188	14	·083	·0069	·00541
000	·425	·1806	·14186	14½	·077	·0059	·00466
00	·380	·1444	·11341	15	·072	·0052	·00407
0	·340	·1156	·09079	15½	·068	·0046	·00363
1	·300	·0900	·07068	16	·065	·0042	·00332
2	·284	·0807	·06335	17	·058	·00336	·00264
3	·259	·0671	·05268	18	·049	·00240	·00188
4	·238	·0566	·04449	19	·042	·00176	·00138
5	·220	·0484	·03801	20	·035	·00123	·00096
5½	·211	·0445	·03497	21	·032	·00102	·00080
6	·203	·0412	·03236	22	·028	·00078	·00061
6½	·191	·0365	·02865	23	·025	·00063	·00049
7	·180	·0324	·02545	24	·022	·00048	·00038
7½	·172	·0269	·02324	25	·020	·00040	·00031
8	·165	·0272	·02138	26	·018	·00032	·00025
8½	·156	·0243	·01911	27	·016	·000256	·00020
9	·148	·0219	·01720	28	·014	·000196	·00015
9½	·141	·0199	·01561	29	·013	·000169	·00013
10	·134	·0180	·01410	30	·012	·000144	·00011
10½	·127	·0161	·01267	31	·010	·000100	·000078
11	·120	·0144	·01131	32	·009	·000081	·000063
11½	·114	·0130	·01021	33	·008	·000064	·000050
12	·109	·0119	·00933	34	·007	·000049	·000038
12½	·102	·0104	·00817	35	·005	·000025	·000019
13	·095	·0090	·00708	36	·004	·000016	·000012

The gauge, Fig. 3139, manufactured by Elliott Bros., London, is one of the standard Government gauges employed in the Royal Gun Factories. These gauges measure from 36 to 40 in. outside, and 64 in. inside; they read by *vernier* to ·001 of an inch. Some of these gauges are from 4 to 5 ft. in length. The one shown in Figs. 3139, 3140, will measure from 0 to 12 in. *Naylor's gauge* for iron is the one chiefly used by the manufacturers of England, and is similar to the one represented in Figs. 3139, 3140; Naylor's gauge by vernier reads to the $\frac{1}{100}$ part of an inch. The *micrometer gauge*, Fig. 3141, is used to measure wire, sheet metal, and other substances to the ·001 of an inch. It is the most complete little instrument of the sort yet introduced. In using this instrument it should be manipulated with great delicacy, as undue pressure would destroy its accuracy. A gauge of this kind, made by Elliott Bros., for the Royal Mint, reads to the ·0001 of an inch. There are other peculiar contrivances termed gauges, such as the standard for measuring the height of recruits; the instrument employed to measure buckles and indents in targets; standard yards and rods; and the stadiometer used in the army, which require no particular description.

3139.



3140.



3141.

GAUGE, STEAM. FR., *Manomètre*; GER., *Monometer*; ITAL., *Manometro*; SPAN., *Manómetro*.
See DETAILS OF ENGINES. GAUGE. VACUUM-GAUGE.

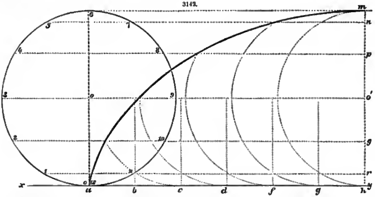
GEARING. FR., *Engrenage, Communication de mouvement*; GER., *Verzahnung, Verbindungstheil, Geschier*; ITAL., *Ruote dentate*; SPAN., *Aparato de trasmision de movimiento*.

Nomenclature of the Curves used for the Form of the Teeth of Wheels.—The form to be given to the teeth of wheels is an essential point in their construction, for on it depends, in a great measure, the regularity of the motion and the wear of the wheels. Originally the cylindrical form was considered the most advantageous, and was exclusively employed. Numerous experiments have shown, however, that the best forms are those of certain curves, which give a result rigorously exact from a theoretical point of view, and very advantageous in practice. These curves, employed according to the nature of the transmission of the motion, are the following;—The common cycloid, the elongated cycloid, the common epicycloid, the elongated epicycloid, the contracted epicycloid, or common hypocycloid, the elongated hypocycloid, the involute of a circle, and the elongated involute of a circle.

The Common Cycloid.—This curve is generated by the point a in the plane of the circle o which, while turning about its own axis, rolls upon the straight line $x\,y$. This point a and the circle o are called the generators of the curve, the line $x\,y$ being usually called the directrix. The curve is complete when, after a complete revolution of the generating circle, the point a again touches the directrix, Fig. 3142.

Construction.—The generating circle o being given, and the line $x\,y$ upon which it is to roll, divide, beginning at the point a, the circumference of the circle into a sufficient number of equal parts $a\,1$, $a\,2$, $a\,3$ . . . to allow of each of them being considered as a straight line; and mark on the line $x\,y$ the same number of parts $a\,b$, $b\,c$, $c\,d$ . . . equal to the divisions on the circumference. With the radius $o\,a$ describe circles to the directrix in the points b, c, d . . . ; their intersection with the parallel lines drawn through the points 1, 2, 3 . . . gives points in the cycloid. It only remains to join them by a continuous curve. It will be noticed that the centres of all the circum ferences must be on a line parallel with the directrix, and drawn through the point *o*, and upon the perpendiculars raised from the points *b*, *c d* . . .

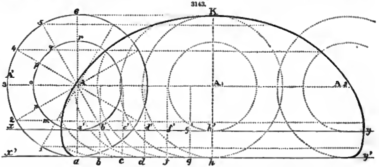
3142.



When the generating circle is tangent in *h* the half of its circumference will be developed upon *x y*, and consequently we have obtained the half of the curve sought. The other half may be easily determined by taking *n* 5″, *p* 4″ . . . equal to *n* 5′, *p* 4′ . . . As only a very small portion of the cycloid is ever used, it will be sufficient for purposes of gearing to determine a single element.

The Elongated Cycloid.—This curve is generated by a point *a* in the circle A′ concentric with a circle A, which rolls upon a straight line *x y*, called the directrix, Fig. 3143. The point *a* and the circle A′ are called the generators of the curve. The generating circle being invariably connected with the circle A, and dragged along with it in the motion of rotation, the latter might be called the conducting circle.

3143.



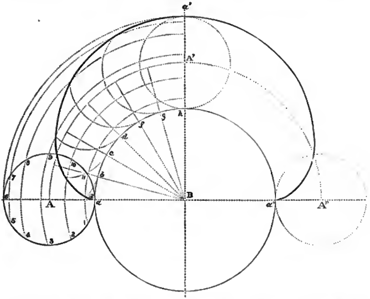
Construction.—The generating point being at starting on the perpendicular line drawn on the directrix through its point of contact with the circle A, divide the circumference of this circle into a sufficient number of equal parts to allow of each of them being considered as a straight line. Mark upon the line *x y*, beginning at the point *a*′, the lengths *a*′ *b*′, *b*′ *c*′, *c*′ *d*′ . . . equal to one of the divisions on the circumference. This done, with the radius of the generating circle, describe circumferences tangent to *x*′ *y*′ in the points *b*, *c*, *d* . . . By producing the radii A *m*, A *n*, A *o*, A *p* . . . we get upon the circumference A′ the points of division 1, 2, 3 . . . ; through these points draw lines parallel with the directrix, their intersection with the corresponding circumferences already described gives points in the curve.

When the half of the circumference A is developed upon the line *x y*, the generating point has described the half of the elongated cycloid; the other may be found by analogous construction, or, since it is symmetric with the first with respect to the perpendicular K *h*, a certain number of points may be determined by the method already explained for the common cycloid.

The Epicycloid.—This curve is generated by the point *a* in the circumference of a circle A, Fig. 3144, which revolves along the circumference of a circle B, called the directing circle. The point *a* and the circle A are called the generators of the curve.

Construction.—If we suppose the diameter of the generating circle equal to the half of that of the directing circle, it is evident that, in this case only, the point *a* will have described the complete epicycloid when the circle A has arrived at that position upon the diameter *a a*″ which is opposite that from which it started, that is, when it is tangent in a''. The construction given for this particular case is the same in all the others, and gives consequently an analogous curve.

3144.



Divide now, beginning at the point a, the circumference A into a considerable number of equal parts, each of them having to be considered as a straight line. In the same way, beginning at the point a, mark upon the circumference B divisions equal to the preceding, these having to represent the development. With the radius of the generating circle describe a series of arcs tangent to the directing circle in the points $a, b, c, d \ldots$; then from the centre B with the radii B 1, B 2, B 3 . . ., describe circumferences. Their intersection with the corresponding arcs, tangent to the circle B, gives points in the curve. One of these points, m for example, is a position of the point a, for the latter must belong to the circumference tangent in c. Also when the point a has arrived at c, the generating point will evidently be upon the circumference passing through the point 3; it must, therefore, be at m, the point of intersection of the two circumferences.

The half of the curve will be described when the generating circle is tangent to the circle B at the end of the radius perpendicular to the diameter $a\,a''$. The other half of the epicycloid may be obtained by placing, by means of parallels with $a\,a''$, a sufficient number of the points of the preceding half, in a symmetrical position with respect to B a'.

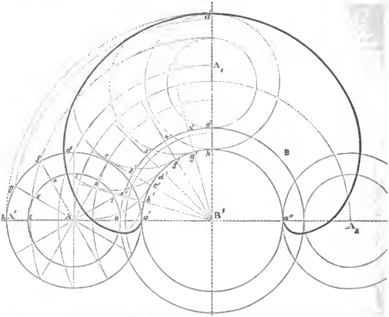
The Elongated Epicycloid.—This curve is described by a point a in the plane of a circle A′, concentric and invariably connected with a second circle A, which revolves along the circumference of a third circle B, called the directing circle. The point a and the circle A are the generators of the elongated epicycloid, Fig. 3145.

Construction.—Having taken the diameter of the circle A equal to the radius of the directing circle B, the circumference of the former will be completely developed upon that of the latter when it occupies the position opposite the extremity of the diameter $a\,a''$, and the point a will have described the whole curve when it is again in contact with the circumference B′. Now, to obtain points in the curve, divide the circumference A into a sufficient number of equal parts 0, 1. 1, 2. 2, 3 . . . to allow of each of them being considered as a straight line. Mark, beginning at the point a, these same divisions upon the directing circumference; then, through the points 1′, 2′, 3′ . . . draw radii which give upon the circumference B′ the points $b', c', d' \ldots$ With the radius of the generating circle describe circumferences tangent in these points.

Having produced the radii at the points of division 1, 2, 3 . . ., and obtained upon the generating circle the corresponding points $b, c, d \ldots$, from the centre B with the radii B b, B c, B d . . ., describe circumferences the intersection of which with the arcs already drawn gives points in the elongated epicycloid.

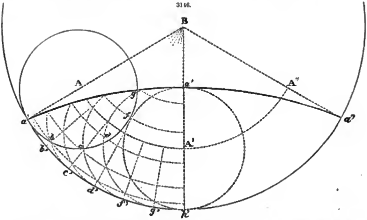
The point a will have described the half of the elongated epicycloid, when the diameter $a'\,h'$ of the generating circle coincides with the radius B h' produced, perpendicular to $a\,a''$. The other half of the curve may be obtained by an analogous construction, or by placing the points obtained in a position symmetrical with respect to a' B′. To facilitate the construction, we mark equal parts upon the circumference A, but it may be remarked that these parts may be unequal, provided they be transferred accurately to the directing circumference.

3145.



Common Hypocycloid.—This curve is described by the point *a* in the plane of a circle A which revolves about its own axis along the concave side of a circumference B. The circle B is called the directing circle, the circle A and the point *a* are the generators of the curve, Fig. 3146.

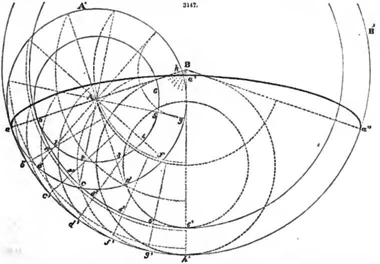
3146.



Construction.—The line of the centres B A determines by its intersection with the circumference B, the generating point *a*. Beginning at this point, divide the circumference A into a great number of small parts *a b*, *b c*, *c d* . . . , which may be considered as straight lines. Beginning at the same point a, mark an equal number of these parts upon the circumference B. With the radius of the generating circle describe a series of arcs tangent in the points $b', c', d' \ldots$, and from the centre B, with the radii Bb, Bc, B$d \ldots$, describe arcs the intersection of which with the former gives points in the hypocycloid. The centre of the circle A describes during its revolution a portion of a circle A A′ A″, concentric with the circle B; this is the common locus of the centres of all the arcs tangent in the points $b', c', d' \ldots$ If we wish for greater exactness than that which we obtain by considering the elements of the generating circle as straight, we may determine the development of one of them, and use this length for $a b', b' c', c' d' \ldots$ This precaution is useful when the radius of the generating circle is very small with respect to the radius of the directing circle, that is, when the elements, however small they may be, form a decided curve.

Elongated Hypocycloid.—This curve is generated by the point a in the plane of a circle A′ invariably connected with a circle A, which revolves about its own centre along the inner side of a third circle B, called the directing circle, Fig. 3147.

3147.



Construction.—The line of the centres A B determines by its intersection with the circumference B′ the first position of the generating point a. Beginning at the intersection o of this line of the centres with the circumference B, divide the circumference A into a sufficient number of equal parts 0. 1, 1. 2, 2. 3 . . . , each of them having to be considered as a straight line. Mark, in the same way, beginning at 0, upon the circumference B, an equal number of divisions 0. 1′, 1′. 2′, 2′. 3′ . . . representing the development of the preceding. The radii being now produced from the points of division 1′, 2′, 3′ . . . , give upon the circumference B′ the corresponding points $b', c', d' \ldots$; with the radius of the generating circle, describe arcs tangent in these points.

Having produced the radii A 1, A 2, A 3 . . . , and obtained upon the circumference A′ the points of division $b, c, d \ldots$, from the centre B with the radii Bb, Bc, B$d \ldots$, describe a series of arcs the intersection of which with the preceding gives points in the elongated hypocycloid.

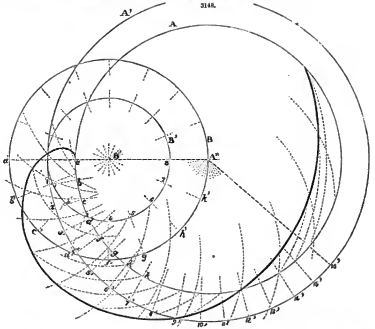
When the point o arrives at the position c', the generating point a will be at a', and will have described the half of the curve sought. The other half may be obtained by an analogous construction, or by transferring a sufficient number of the points of the former to a symmetrical position with respect to Bh'.

Another Elongated Hypocycloid.—Let there be two circles, A and A′, invariably connected together and forced to turn about their common centre A″. If in this revolution the circle A is made to follow the contour of a third circle B′, called the directing circle, the point a of the circle A will describe an elongated hypocycloid, Fig. 3148.

Construction.—Beginning at the point of intersection o of the circumference A with the line of the centres A″ B″ produced, mark upon the circumference B′ a sufficiently great number of divisions to allow each of them to be considered, without an appreciable error, as a straight line. Mark an equal number of these divisions upon the circumference A, and draw the radii from the points 1′, 2′, 3′, 4 . . . It will be seen that the centre A″ of the generating circle describes in its revolution a circle B concentric with B′. Producing the radii from the points of division 1, 2, 3, 4 . . to the circumference of this circle, we obtain the corresponding points $a', b', c', d' \ldots$ From each of these points with the radius of the circle A′ describe arcs, and from the point B″ with the radii B″b, B″c, B″$d \ldots$, describe other arcs the intersection of which with the former gives points in the curve sought.

One of these points, m for example, must occupy one of the positions of the point a, for the latter, remaining upon the generating circle A′, must belong to the arc described from the point c′ with a A″ as a radius; it must also be upon the circumference described from the point B′ with B″ p as a radius; it can, therefore, be only at their point of intersection.

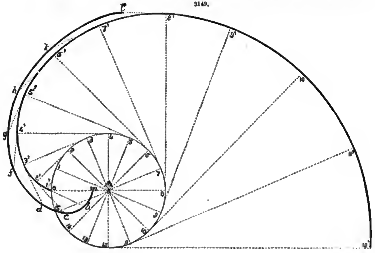
3148.



Involute of a Circle.—This curve is generated by the end of a tangent to the circle made to touch the circumference in all its points successively.

Let o A, Fig. 3149, be the radius of the given circle, and o the first point of contact of the

3149.



tangents. Beginning at this point, mark on the circumference a sufficient number of equal parts 0.1, 1.2, 2.3, 3.4 . . ., to allow of each being considered as a straight line. Draw the tangents from the points of division, and, upon the first, mark one of the elements or divisions of the circumference, upon the second two of these elements, upon the third, three, &c. Join by a regular curve the points 1′, 2′, 3′, 4′ . . ., thus obtained.

Elongated Involute of a Circle.—If at each of the points 1′, 2′, 3′, 4′ . . ., Fig. 3149, we draw perpendiculars to the tangents, and mark off on each of them a constant length, equal to *o m*, for example, the points obtained, *b*, *c*, *d*, *f* . . . belong to an elongated involute of a circle.

Remark.—The common involute may be wholly traced by the compasses, for any element *q*′, 10′ has its centre at the point of intersection *p* of the tangents *q*, *q*′, and 10, 10′. The other curves, the means of drawing which we have already given, may be obtained by means of a little piece of wood, the arrangement of which for each case may be easily imagined.

Dimensions of the parts of Gearing considered both in Detail and as a Whole.—Object of Gearing, its Advantages.—A toothed wheel is a circle or disc furnished along its contour with projecting pieces called teeth, designed to transmit to another toothed wheel a determinate force, the direction and velocity of which are known.

Gearing is used;—

1. To transmit the continuous circular motion of a shaft to another shaft fixed at a short distance from it. When the shafts are parallel the gearing is called straight or spur-gearing. If the shafts make an angle with each other, the motion is transmitted from one to the other by means of conical or bevel-gear.

2. To transform the continuous circular motion of a shaft into a rectilineal motion of a plane-toothed surface.

3. To transform the continuous circular motion of a shaft into another circular motion of an endless screw, and *vice versâ*. In all cases the axis of the toothed wheel and that of the endless screw are placed in two perpendicular planes, and not in the same plane as in the case of conical gear.

4. The ascending motion of mill-hammers and other similar contrivances is obtained by the transformation of the continuous circular motion of a shaft by means of cams. The use and construction of these cams rest upon principles similar to those which have led to the application and to the improvement of gear.

The first attempts to transmit the motion of one shaft to another was by means of friction. This friction was produced upon cylinders or drums fixed upon the shafts. The rapid wear of the drums required them to be frequently changed, or the shafts to be brought nearer together. These grave defects, and the difficulty of removing them, led to the adoption of teeth, which have lately undergone great improvement. If these teeth are carefully constructed, we may obtain very exactly relations of speed determined beforehand, a gentle and uniform motion, and a sufficient duration of material. The use of gearing enables us to make a large number of transmissions in a small space; its application is especially remarkable in watch and clock work, where it is carried to a high degree of perfection.

Relation of Velocity to be obtained.—Primitive Circles, or Pitch-Lines.—When a rotary motion is transmitted from one shaft to another, the object always is to obtain a certain determinate velocity. This velocity results from two conditions, which are mutually dependent; 1, the primitive diameter of the wheels; 2, the respective number of the teeth of each of them.

By primitive or pitch-circles we mean those which are tangent to each other at the point *a*, Fig. 3150, where the contact of the two teeth which act normally, one as the power, the other as the resistance, takes place, that is, where the principal force is exerted. The relation between the radii *o a*, *o′ a* of the primitive circles must always be the same as that of the velocities; thus if it be required to make one of the wheels revolve three times while the other revolves only once, the latter must have a radius equal to three times the radius of the former.

To calculate the primitive diameters we must know;—

1. The distance of the shafts measured from axis to axis;

2. The relation between the velocity of the wheel and the velocity which the pinion is to have. The radii of the wheels must be in inverse proportion with the velocities. Indeed the circumferences are to each other as the radii; and as the numbers of teeth depend on the circumference, these numbers are also in the same proportion as the velocities. Again, as each tooth of the wheel propels forward one of the pinions, it is evident that the number of revolutions will be inversely as the radii.

Let n be the number of revolutions of the wheel and r its radius, r' the radius of the pinion and n' the number of revolutions it is to make a minute.

According to what we have said above, we have

$$n : n' :: r' : r. \qquad [1]$$

Let us suppose that $n = 14$, $n' = 42$, and the distance of the centres $= 1^{m}\cdot 30 = r' + r$.

Proportion [1] may be put under the form

$$n + n' : n' :: r' + r : r,$$

or

$$56 : 42 :: 1^{m}\cdot 30 : r,$$

whence

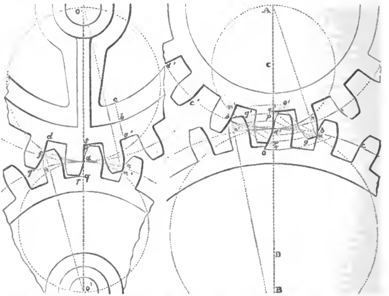
$$r = \frac{1^{m}\cdot 30 \times 42}{56} = 0^{m}\cdot 975,$$

and

$$r = 1^{m}\cdot 30 - 0\cdot 975 = 0\cdot 325.$$

In some cases, the velocity to be obtained differs greatly from that which we have at our disposal: if we employed only two wheels, we should have to reduce the dimensions of the pinion too much, and sometimes to increase beyond measure those of the wheel. In such cases, we interpose between the two shafts a series of wheels and pinions, the combination of which gives the result desired. But this means should be employed only in case of absolute necessity, for we must not forget that these mediums absorb a considerable quantity of the motive force.

3150.



Let us suppose that the shaft B is to make sixty-four revolutions while the shaft A makes one. If, for the sake of simplicity in execution, we make all the wheels of the same diameter, and the pinions also equal to each other, we extract a root of the number of revolutions required; the index of this root will represent the number of couples to be employed, and the root itself will denote the constant proportion between the primitive diameter of the wheels and those of the pinions. Thus if the square root of 64, which indicates the employment of two couples and gives as the proportion of the radii 8 : 1 does not appear applicable to the case required, we may take the numbers given by the cube root, that is, three couples in the proportion of 4 : 1.

When particular arrangements oblige us to employ different proportions for the couples of gearing, we resolve the number of revolutions to be obtained into several factors, choosing those which are the most convenient. Thus for the case we have alluded to above, three couples in the proportions of 2, 4, and 8 would give the velocity required.

Dimensions and Form of the Teeth.—In constructing the teeth we must have in view;—1, the thickness of the tooth; 2, the space between the teeth; 3, the distance of the teeth; 4, the number of the teeth; 5, the depth of the face; 6, the depth of the shoulder; 7, the form of the teeth; 8, the total depth.

1. *Thickness of the Teeth.*—The thickness of the teeth depends entirely upon the force they have to bear and the nature of the material of which they are made. The force should always be taken for the case in which the wheels would have to transmit the maximum power of the motive engine. In calculating the thickness of the teeth the results of experience must be referred to, and we must suppose the case of only one tooth in contact, that is, supporting alone the whole force.

Example.—A pinion makes six revolutions while the wheel which drives it makes one; the distance of the centres is $2^{m}\cdot30$; the work effected is 940 kilogrammètres, and the wheel has a velocity of five revolutions a minute. Determining the radius of the wheel in the way we have described, we find it to be equal to $1^{m}\cdot917$.

The velocity at the primitive circumference or pitch-line will therefore be

$$\frac{1\cdot917 \times 2 \times 3\cdot14 \times 5}{60} = 1^{m}\cdot003.$$

The force is found by dividing the work to be transmitted by the velocity

$$\frac{940}{1\cdot003} = 937 \text{ kilogrammètres.}$$

Now, to find the thickness of the tooth, we multiply the square root of 937 by a coefficient determined by experience.

For cast iron	0·105
For bronze	0·131
For hard wood	0·145

Thus the teeth being of cast iron, their thickness will be $0{\cdot}105 \times \sqrt{937} = 0^{m}{\cdot}032$.

2. *Space between the Teeth.*—If the teeth were made with mathematical precision, the space between two of them measured upon the pitch-line might be made equal to the thickness. When the teeth are filed the space is taken equal to the thickness plus $\frac{1}{15}$. This fifteenth is intended to correct the defects resulting from the imperfection of the work. When the teeth are unsmoothed or of different materials, the space is made equal to the thickness plus $\frac{1}{10}$.

3. *Distance of the Teeth.*—The arc of the primitive or pitch-circle comprising a space and a tooth, that is, the distance from the outside edge of one tooth to the outside edge of the next, constitutes what is called the distance of the teeth.

It is evident that this distance must be the same upon the wheel and upon the pinions, and that it must be taken an exact number of times upon each of the two circumferences.

4. *To Calculate the Number of the Teeth.*—Let m' be the number of the teeth on the wheel; m the number on the pinion; a the distance of the teeth, and r the radius of the wheel. We will continue to operate with the values given in the preceding example. The number of teeth is evidently equal to the pitch-line divided by the distance of the teeth. Therefore

$$m = \frac{2\pi r}{a};$$

but $$a = 0^{m}{\cdot}032 + (0{\cdot}032 + 0{\cdot}003) = 0^{m}{\cdot}067,$$

and $$r = 1^{m}{\cdot}917;$$

therefore $$m = \frac{6{\cdot}28 \times 1{\cdot}917}{0{\cdot}067} = 180.$$

This number is exactly divisible by the ratio 6 of the radius of the wheel and that of the pinion, which is a necessary condition, since the numbers of the teeth must be to each other as the primitive or pitch-circles, and consequently as their radii. Besides this, symmetry and readiness in putting together require, if the wheels are in several pieces, that the number of teeth be exactly divisible by the number of the arms of the wheel. In the present case, supposing six arms, the number 180 would fulfil the second condition also. In the contrary case, we take the number next smaller than that given by calculation, which is at once divisible by the number of arms and the ratio between the radius of the wheel and that of the pinion. This modification can never be attended with any objectionable result, since the teeth are taken a little stouter than the preceding operation indicates.

5, 6, and 7. *Shoulder and Face of the Teeth; Form of the Profile.*—The part $d f$ of the profile included between the primitive circumference and the base of the tooth, is called the shoulder; it is always formed by the radius from the point f, Fig. 3150. The part $f g$ of the same profile standing beyond the primitive circle is called the face of the tooth.

The depth of the shoulder depends on that of the face, and this latter is determined by considerations which we shall come to presently.

In the motion of two wheels, the shoulder alone of a tooth comes into contact with the faces of the teeth of the other wheel. If the gear turned always in the same direction, in other words, if the same wheel always drove, this one alone would require for the faces of its teeth the particular forms adopted in their construction. But in almost all cases the wheels drive and are driven alternately; thence arises the necessity of providing each of them with a face.

8. *Limit to the Teeth.*—The limit to the depth of the teeth results from important considerations, which we will now proceed to consider merely from a practical point of view.

The teeth must be long enough to allow two couples at least to be in contact at the same time, for if the force be exerted upon only one tooth of each wheel, the whole work of a mill or of a machine will be subordinated to the rupture of this tooth. If, on the other hand, too large a number of teeth be in contact at one time, we shall find that their contact is one in appearance rather than in reality, for it is almost impossible to execute the work with such precision that all the teeth shall act simultaneously. Thus care must be had to have two teeth always ready to come into contact when two others are on the point of quitting each other. This result is obtained by limiting the teeth, the length of which depends upon what is sometimes called the driving arc. By driving arc is meant that arc in which a tooth moves while it is engaged in driving the one against which it presses. Thus in Fig. 3150 this arc would be the arc $m a n$ described upon the pitch-line by the point n from the moment when one tooth begins to press upon its neighbour till the moment when it ceases to act. In practice, and for gearing of ordinary dimensions, this arc may be taken equal to the distance of the teeth, on each side of the line of the centres.

Thus to limit the teeth of the wheel, take upon the pitch-line of the pinion the arc $a m$ equal to the distance of the teeth, and draw the radius $o' m$, cutting in m' the circumference described upon $o' a$ as a diameter. The circumference described from the centre o with $o' m$ as a radius will limit all the teeth of the wheel. This circumference and that which determines the extremity of the teeth of the pinion meet the line of the centres in the points $g p$; beginning at these points, mark upon the line of the centres towards o' and o, the lengths $q r$ and $p s$, equal to about $\frac{1}{4}$ of the depth of the face for large gear, and $\frac{1}{3}$ for small gear. Then from the points o and o' with $o s$ and $o' r$ as radii, describe circumferences forming the bottom of the spaces between the teeth, and determining in profile the base of the teeth. To avoid a re-entering angle, that which is formed by the bottom of the space and the side of the tooth is slightly rounded.

This method of limiting the teeth is quite practical, and may be modified to suit the cases of the epicycloid and the involute.

Remark.—It may happen that we are obliged to employ a pinion of a very small diameter to transmit a great force, or a wheel of a very large diameter for work of inconsiderable importance. In the former case, if the driving arc were equal to the distance of the teeth on each side of the line of the centres, the teeth would be very long, and would, consequently, become too thin at their extremities. We must, therefore, take the arcs described during contact equal to ¾ or ⅔ or even ½ if necessary. In the case in which the wheels are large to transmit a small force, we should obtain by the foregoing method, teeth much too short; we must therefore take the arc of contact equal 1½ the distance of the teeth. It is advisable, however, if the size of the teeth be increased, not to give it more than $1^{\mathrm{m}}\cdot 5$ of the breadth taken upon the pitch-circle.

If the dimensions of a pinion are such that the number of teeth would be less than fifteen, it is preferable to employ several couples. The endless screw may be substituted for the pinion when the wheel is to be driven by it, especially if the force to be transmitted is great and the velocity to be obtained rather low.

It frequently happens that a wheel with wooden teeth works into a pinion wholly of metal. In this case the wooden teeth are evidently stouter than the iron teeth, since their thickness b is given by the formula $b = 0\cdot 143\sqrt{P}$, whilst that of the teeth of the pinion is expressed by $b = 0\cdot 105\sqrt{P}$, P representing the force to be transmitted. It follows from this that the spaces on the pinion are greater than those on the wheel to give passage to the cogs. Nevertheless, the distance of the teeth must remain the same in both wheels.

Breadth of the Teeth; particular arrangements.—The length of the teeth in the direction of the axis is commonly equal to four, five, or six times the thickness upon the pitch-line, according as the velocity is to be small, greater than $1^{\mathrm{m}}\cdot 75$ a second, or the gear constantly wet. It does not interfere in any way with the wear of the gear or the regularity of the motion, to increase the breadth of the teeth, or at least to increase it in small degree above that indicated. Generally when this breadth exceeds certain limits, in large wheels with wooden teeth, the teeth are separated into two equal parts in the direction of the breadth of the circumference of the wheel, and these parts are so arranged that one is opposite the space between it and two others. In this way we have upon the same wheel two sets of gear quite distinct though perfectly similar and acting together. By this means we get between the mortises into which the teeth are fixed, a solid space in the middle of the rim of the wheel, which adds to its strength. When a wheel so constructed works into an iron pinion, the model of the latter is made so as to have its teeth placed inversely as those of the wheel.

Gear intended to transmit to four pumps the work of an engine of 60 horse-power is arranged in the manner described above, and each part has a breadth equal to four times its thickness upon the pitch-line; this gives eight times the thickness for the total breadth, supposing the teeth not crossed, but made of a single piece or placed end to end.

The parts of the teeth that enter the mortise are a little smaller than the teeth themselves measured at the base, so that the shoulder resulting from this difference rests upon the periphery of the wheel. The ends of the teeth project on the inner side by a quantity equal to the depth at the crown measured in the direction of the radius. There result from this, spaces having the form of equal trapeziums, into which are placed, in the manner of dove-tailing, pieces of wood that are afterwards fixed to the teeth by means of screws.

Dimensions of the Periphery, and Number of Arms of Toothed Wheels.—Instead of being placed upon the periphery of a solid disc, the gear forms part of an iron rim $a' b$, Fig. 3150, connected with the axle by a certain number of arms. The breadth of this rim is equal to the breadth of the teeth when the whole is of metal. When the teeth are of wood the rim is made broader by a quantity equal to twice their thickness, in order that it may not be too much weakened by the mortises; its thickness should be at least equal to that of the tooth. In gearing which is exposed to violent vibration, these dimensions must be increased; experience and the quality of the metal must in such cases determine the degree.

Whatever be the section of the rim, it is provided on the inside and in the middle of its breadth with a moulding or rib $b\,c$, the two dimensions of which, projection and thickness, are equal to the thickness of the rim itself. By proceeding in the above manner for wheels of a large diameter intended to transmit a small force, we should obtain too thin a crown, and liable to twist out of shape while cooling after casting. To avoid this defect it must be made a little stouter, and if necessary the number of the arms increased.

The number of arms to be given to wheels depends on their diameter. Those of $1^{\mathrm{m}}\cdot 50$ and less have four arms, those of from $1^{\mathrm{m}}\cdot 50$ to $2^{\mathrm{m}}\cdot 50$ have six, and those from $2^{\mathrm{m}}\cdot 50$ to 5 mètres have eight. If it is necessary to employ wheels of from 5 to 7 mètres, a case that seldom occurs, we may increase the number of arms to ten.

It is customary to give to the arms of wheels a section exactly equal to that of the rim, and they are strengthened on each side by a rib of the same thickness as that of the crown, and running into the latter. If any space remains between the bases of the arms, the rib runs round the centre or nave.

Methods of Tracing the various Forms of Gear.—Epicycloidal Gear.—We have shown the different principles upon which the construction of gear and the calculation of its dimensions rest; we will now point out the rules generally followed in tracing it.

It is known that when a circle is made to roll upon another circle, any point in its circumference describes an epicycloid. The motion which produces the curve is subject to the same laws as that of two tangent circumferences revolving about their centres when the latter are fixed. It follows from this that if we give the epicycloidal form to the profile of the teeth, the wheels will be driven by each other in the same manner as they would be by simple contact. This form is sometimes adopted. Suppose now we have to construct a spur epicycloidal gear with the following data ;—

Distance of the centres	$0^{m}\cdot267$
Ratio of the velocities	$\frac{3}{5}$
Distance of the teeth	$0^{m}\cdot035$

Take A B, Fig. 3150, equal to $0^{m}\cdot267$, and divide this line into two parts *a* A and *a* B, so that they may be to each other as 3 is to 5. The circumferences described with *a* A and *a* B as radii are the pitch-lines of the gearing. The length or development of the circumference of the wheel is expressed by $2\,\pi\,a\,B$, or $6\cdot28 \times 0\cdot167 = 1^{m}\cdot049$; and the number of teeth is given by $\frac{1\cdot049}{0\cdot035} = 30$.

The pitch-line of the pinion being $2\,\pi\,a\,A$, or $6\cdot28 \times 0\cdot100 = 0^{m}\cdot628$.

The number of teeth is $\frac{0\cdot628}{0\cdot035} = 18$.

The division of $1\cdot049$ and $0\cdot628$ by the distance of the teeth cannot be exactly performed, but the approximation is such that the error of calculation when spread over all the divisions may be neglected. Also by taking the radius *a* B equal to $0\cdot167$ instead of $0\cdot66875$, and the radius *a* A equal to $0\cdot100$ instead of $0\cdot100035$, we make the error $\frac{1}{2}$ millimètre at the most.

Mark now, beginning at the point of contact *a* upon the circumference *a* B, the lengths *a b*, *b c*, *c d* . . . , equal in development to $0^{m}\cdot035$; mark off also these divisions upon the circumference *a* A, beginning at the same point *a*, then, upon the radii *a* B and *a* A as diameters, describe circumferences, and determine a fraction *a o* of the epicycloid generated by the point *a*, supposing the circumference *a* D to roll upon the primitive circumference or pitch-line of the pinion. The face of the tooth of the pinion will be taken upon *a o*, and the shoulder upon the radius *a* A. If we now draw the radii through the points of division, and to each of these points bring the curve *a o* with its concave side turned towards the axis of the tooth, we shall get all the profiles. The faces of the teeth of the wheel are determined by constructing the portion *a a′* of the epicycloid described by the point *a* while the circumference *a* C is rolling upon the pitch-line of the wheel, and by bringing this curve to the end of the radii of the points *b*, *c*, *d* . . .

The depth of the teeth depends, as we have seen, upon the duration of contact or driving arc. If it be required to have always three teeth engaged, this arc must be made equal to the distance of the teeth of each side of the line of the centres. Thus *a* K being the distance of the teeth, the epicycloid which begins at K must be produced until it meets the circumference D *a* in *m*. From the point A as a centre, with A *m* as a radius, describe a series of arcs such as *m q*, which will limit all the teeth of the pinion. This operation is performed in the same manner for the wheel. The circumferences which limit the teeth of both wheels meet the line of the centres in the points *p* and *q* ; mark off, beginning at these points and in the direction of the centres, the lengths *p q* and *p′ q′* equal to $\frac{1}{4}$ or $\frac{1}{6}$ of the projection of the tooth upon the pitch-line. The circumferences described from the points B and A with B *q* and A *q′* as radii, will determine the bottom of the spaces between the teeth on the wheel and on the pinion. It only remains then to round slightly the angles formed by the periphery of the wheel and the sides of the teeth.

Remark.—Epicycloidal gear has the grave defect of being able to drive only one wheel, or if it drive several, they must be all of the same diameter. The faces of the teeth of the pinion are in fact obtained by the rolling upon its primitive circumference of a circle having as its diameter the radius of the primitive circle of the wheel. Thus the curve generated for different pinions will vary with their diameter. Again, the faces of the teeth of the wheel are determined by the rolling upon its primitive circumference of different circles having as diameters the radii of the pinions. The curves generated all comply separately with the requirements of the question, but none can be employed to drive the system. Consequently, it is better in this case to renounce the form of the epicycloid, and to employ the involute, which does not possess the same defect, as we shall have occasion to show presently. The epicycloidal form may be made use of, however, in the case of which we have been speaking, by taking a generating circle having as a diameter the radius of the smallest pinion, and by causing it to roll successively upon the primitive circumference of the wheel, and upon that of each of the pinions which it is to drive.

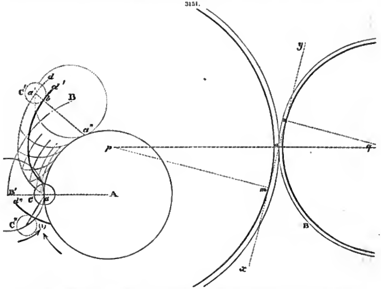
Cylindrical Gear.—This kind of gear which the French call from its form, *lantern gear*, is vicious from several points of view, and its use has been almost wholly abandoned. We will, however, point out the principle of its construction, as cases now and then occur in which it is necessary to employ it.

In this kind of gearing the pinion is provided, in the place of teeth, with cylindrical spindles, such as C, Fig. 3151, all of which have their centres upon the primitive circumference B. The driving wheel is provided with teeth or cogs, the profile of which we are about to determine.

Let A be the primitive circumference of the wheel and B one of the positions of the lantern gear. Suppose the wheel A fixed, and make the circle B roll round it until it comes into the position B′. During this motion the centre of the spindle will evidently describe an epicycloid *d*, and its new position *a′* will belong to this curve, and to the circumference B′. The tracing of gear rests theoretically upon this principle, namely, that the normal common to the point of contact of two conjugate teeth, passes through the point of contact of the primitive circles. If, therefore, from the point *a″* we draw a normal *a″ a′* to the circumference C′, we shall obtain the corresponding point *b* of the tooth of the wheel, that is, the point in which the contact of the cog and the spindle will take place. If now we bring back the circle B′ to its former position B, the point *b* will describe during the motion a curve *d′* equidistant from *d*, which curve gives the true form to be adopted for the profile of the cogs of the wheel A.

It is now easy to show that this kind of gear is defective. Let C″ be a position of the spindle, and *d″* the corresponding position of the tooth in contact. If the motion is in the direction of the arrows, it is clear that the curve d' will not drive the spindle, but that it must be driven by it. Thus, *before the line of the centres, the cog cannot drive the spindle.* If the motion of the wheels is in the contrary direction, it will be seen in like manner that *beyond the line of the centres, the spindle cannot drive the cog.* This kind of gear is, therefore, very incomplete, and it must remain so, for if both branches of the curve were employed, the motion could not pass the line of the centres.

3151.



Practical Method for Epicycloidal Gear.—When the wheels are large and the teeth consequently long, in order to preserve to the curve which forms a part of the profile its particular character, it is usual to execute a portion of the drawing in full size, and to make a model from it, by means of which that form which has been graphically obtained, may be transferred exactly to the wheel.

Generally the teeth are short enough to allow of their curve being considered, without an appreciable error, as an arc of a circle. This radius of this arc must not be taken arbitrarily; and besides this, the centre of curvature must be properly placed. The common radius of the arcs for the teeth of the same wheel, and the geometrical locus of all their centres, are determined by the following construction, which gives a most satisfactory result.

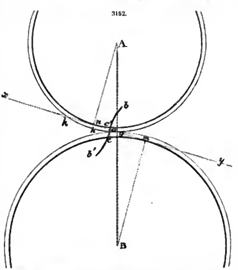
The pitch-lines A and B, Fig. 3151, being given, draw through their point of contact a straight line $x\,y$, making with the line of the centres $p\,q$ an angle of 75°; draw also from the centres p and q to $x\,y$ the perpendiculars $p\,m$, $q\,n$. The magnitudes $a\,m$ and $a\,n$ are the radii, and the points m and n the centres of the arcs which may be substituted for the epicycloid in the profile of the teeth. It is very evident that the circumferences described with $p\,m$ and q a as radii will contain all the centres, and if care be taken to mark them beforehand when the wheels are on the axle, the operation of tracing the teeth will be quickly performed.

Involute Gear.—Let B q and A g, Fig. 3152, be the radii of the pitch-lines of the wheel and pinion, determined according to the data, and in the manner we have already described. Let us take as the profile of the teeth of the pinion, the involute $c'\,b'$ of a circumference, A p interior to A g, and determine the conjugate curve. If we draw through the point g a normal $x\,y$ to $b'\,c'$ the point of intersection a is the point in the conjugate tooth where its contact with that of the pinion is to take place. Again, as it is an established geometrical fact that every normal to the involute is tangent to the evolute, it follows that the line $x\,y$ is tangent to the circumference A p at the end of the radius A n. Having drawn the perpendicular B m, and taking this line as a radius, we describe a circumference, the involute $c\,a\,b$ of which is the curve conjugate with $c'\,a\,b'$. It may be easily demonstrated that the evolute of $c\,a\,b$ must be the circumference B m.

The triangles a a q, B $m\,g$ being similar, their homologous sides are proportional; but as A g, B q, and A n are constant, B m remains constant, and must be the radius of a circle. The two radii A a and A m are to each other as those of the pitch-lines A g and B g. The locus of the points of contact of the teeth is the line $x\,y$; but in practice, contact can take place only on the portion $m\,m$ of this line. Theoretically, the angle $a\,g\,x$ may be arbitrary, but it is usually made equal to 75°. Some millwrights take from the point g upon the pitch-line A g, an arc $q\,h$ K equal to twice the distance of the teeth; the line Kg produced is then the common tangent of both circumferences. We have now only to divide the pitch-lines in the manner described when treating of epicycloidal gear, and to shape the teeth by the involutes passing through the points of division.

In this kind of gear the driving force is exerted throughout the whole length of the line *m n*, and, consequently, before and beyond the line of the centres. It may be remarked that a wheel of this kind plays no part in the construction of the conjugate wheel; it follows, therefore, that it possesses the valuable property of being able to drive at once several wheels of the same kind, of different diameters. This system works well after the shafts have been forced a little beyond their original position, and is, therefore, suited to rolling mills and similar machines.

3162.



Inner Gearing.—When the motion of two parallel shafts is to take place in the same direction, we cannot employ two wheels both toothed on the outer circumference; one of them, necessarily the larger, is toothed on the inner side. In this system the profile of the teeth differs from that which we employ in the other cases, and that on account of the following considerations.

In epicycloidal gear the shoulder of the tooth is generated by the rolling, on the inner side of the primitive circumference, of a circle having only half its diameter. The force is generated by a point of a circle rolling externally upon the same circumference. The forms of the shoulder and face may be made to run into each other, and it is easy to cut the material to the profile given by the drawing. If we adopt the same method for the inner gear, impossibilities arise in practice which oblige us to abandon the system of reciprocal shoulders. The only admissible solution of the difficulty consists in giving shoulders to the teeth of the pinion and curves to the wheel.

Suppose now we have to construct an inner gearing with the following data;—

Distance of the centres	$0^{m}\cdot100$
Distance of the teeth	$0^{m}\cdot035$
Ratio of the velocities	$\frac{1}{2}$

If r and n represent the radius and the number of revolutions of the wheel, r' and n' the radius and number of revolutions of the pinion, we have the proportion $r : r' :: n' : n$.

According to the data, $n' = 2\,n$; therefore $r = 2\,r'$.

But the distance of the centres $d = r - r' = 2\,r' - r' = r'$; therefore the radius of the pinion is equal to d or $0^{m}\cdot100$; and that of the wheel $r = 2\,r' = 0^{m}\cdot100 \times 2 = 0^{m}\cdot200$.

Having acquired these data, continue the operation in the following way;—

Describe the pitch-lines A a and B a tangent in a. From this point a divide the pitch-line of the wheel into parts $a\,b$, $b\,c$, $c\,d$ . . . , equal to the distance of the teeth or to $0^{m}\cdot35$. Mark in the same way, beginning at the point a, these same divisions upon the circumference of the pinion in $a\,b'$, $b'\,c'$, $c'\,d'$ . . . , then, having determined the thickness of the teeth with respect to the space between them, transfer it from the points a, b, c . . . , and a, b', c' . . . , to $a\,1$, $b\,2$, $c\,3$ . . . , and $a\,1'$, $b'\,2'$, $c'\,3'$ . . . Through these points of division in the pitch-line B a, draw radii such as B 1, which determine the profile of the teeth of the pinion, since they consist wholly of shoulder.

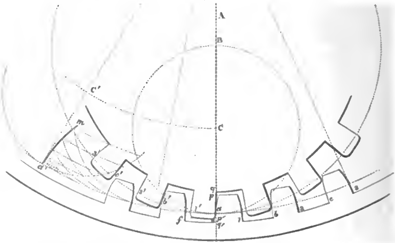
The teeth of the wheel may be obtained in the following manner;—

Upon the radius B a as a diameter describe a circle a C, and, in order not to crowd the diagram, take a second position a' C' of this circle; determine a portion $a'\,m$ of the contracted epicycloid described by the point a', whilst the circle C' a' is rolling upon the inner side of the pitch-line of the wheel. Transfer this curve to all the points of division a, b, c, d . . . , 1, 2, 3 . . . , placing the concave side towards the middle of the tooth. Having completed this operation, it only remains to limit the teeth. Those of the wheel are taken long enough to have at least three couples always in contact, and they are limited by the circumference described upon A p as a radius.

The teeth of the pinion do not terminate at the primitive circumference; they would terminate at the intersection of this circumference with the radii in sharp angles, which would have an injurious effect upon the teeth of the wheel. The profile of the shoulder is continued by arcs of circles, such as $a\,n$, which run into other arcs described with B n as a radius. We have now only the bottom of the spaces between the teeth, or in other words, that portion of the periphery of the wheel that is comprised between two teeth, to determine. The play $p\,g$ and $p'\,g'$ depends on the dimensions of the gear and on the care bestowed on its execution: the amount of play being decided upon, describe with the radii A g' and B g a series of arcs such as $g'\,f$ and $g\,f$. It is well to make the tooth join the periphery by a curve rather than to enter it at right angles.

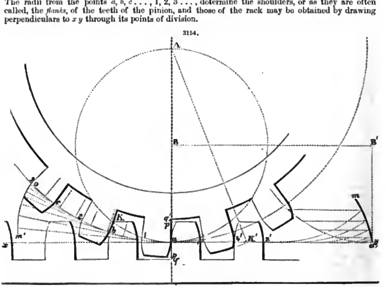
Rack and Pinion.—If we suppose a toothed wheel to increase in diameter indefinitely, the disc which bears the teeth will become a straight surface, and its circular motion will evidently be converted into a rectilinear motion, since in the proportion $r : r' :: a' : n$, r being equal to infinity, n will be equal to zero. The straight surface which receives a rectilinear motion is called a rack.

3153.



Let A *a*, Fig. 3154, be the pitch-circle of the pinion, and *x y* the pitch-line of the rack, tangent in the point *a*. Divide, from the point *a*, the circumference A *a* into parts *a b*, *b c*, *c d* . . . , equal to the pitch or distance of the teeth, and mark these same divisions upon *x y*. From the points *a*, *b*, *c* . . . , and *a'*, *b'*, *c'* . . . , mark the thickness of the teeth at *a* 1, *b* 2, *c* 3 . . . , and *a* 1', *b* 2', *c* 3' . . . The radii from the points *a*, *b*, *c* . . . , 1, 2, 3 . . . , determine the shoulders, or as they are often called, the *flanks*, of the teeth of the pinion, and those of the rack may be obtained by drawing perpendiculars to *x y* through its points of division.

3154.



If now we suppose the line *x y* to move about the pitch-circle of the pinion, its first point of contact will describe an involute of this circle, which should be taken as the profile of the teeth. Having determined a portion *o m'* of the curve, we have only to bring it to each of the points of division in the circumference A *a*.

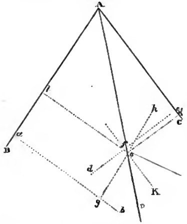
To shape the teeth of the rack we take a portion $a'm$ of the cycloid generated by the point a of a circle Ba, described upon the pinion as a diameter, and rolling upon xy. To limit the teeth of the rack we usually take a length ab' equal to the pitch, describe the cycloid at the point b', and produce it till it meets in K the generating circle Ba. The line parallel to xy drawn through the point K gives the extremities of the teeth. The teeth of the pinion are limited by the circumference of a circle described with the radius bK′, and determined by the position of the point K upon xy. The length ak is usually taken equal to the distance of the teeth, but it may be altered if it is seen that there are too many teeth in contact or that the force is exerted upon too small a number of teeth.

To complete the drawing we take upon the line Aa, beyond the extremities of the teeth, the short distances pq and $p'q'$ to represent the play to be allowed at the bottom of the spaces. The circumference described with Aq' as a radius, and the parallel to xy drawn through the point q, determine the roots of the teeth.

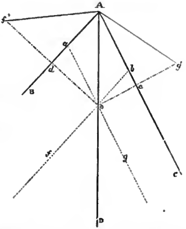
Bevelled Gear.—When it is required to transmit the circular motion of a shaft A B, Fig. 3155, to another A C, making with it any angle B A C, conical or bevelled gear is employed. This kind of gear possesses the same properties as the spur-gear. Suppose, for example, the two axes A B and A C given, as well as the ratio $\frac{m}{n}$ of the number of revolutions, at the points a and c taken arbitrarily upon each of the axes, raise the perpendiculars ab, cd; take upon ab a length ag, and upon cd a length cf, proportional to m and n. Through the points g and f draw gh and fK parallel to the axes; the point of intersection o determines, with the summit A, the generatrix of contact A D. The perpendiculars ok and ol, drawn from the point o to the axes, represent the radii of the bases of the cones or teeth.

Denoting the velocity of the motion by V, the angular velocities of the pinions by V'_1 and V_1, and the radii by R and R′, we have $V = V_1 R$, and $V = V'_1 R'$. But as the velocity V is dependent upon each of the pinions, we get the equation $V_1 R = V'_1 R'$, from which we deduce the proportion $V_1 : V'_1 :: R' : R$. Thus in bevelled as in spur-gear, the angular velocities are inversely proportionate to the radii.

3155.



3156.

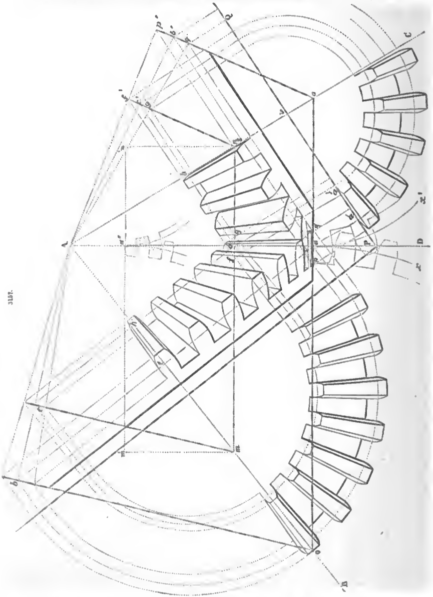


But, the two axes and the ratio of the velocities being given, we may determine the generatrix of contact in the following manner;—Upon the axis A B, Fig. 3156, take Aa equal to m, and upon the axis A C, $ab = n$; through the points a and b draw ag, bf, parallel to the axes; the point o in which they meet belongs to the generatrix of contact. If we let fall upon the axes through the point o, the perpendiculars oc, od, we get two similar triangles, which give the proportion $od : oc :: oa : ob$; but $oa = n$ and $ob = m$; substituting these values, we have $od : oc :: n : m$. Therefore the radii od, oc, or the diameters of', og', fulfil perfectly the condition required.

Let us now execute a drawing of two bevelled wheels by means of the following data;—The angle B A C, Fig. 3157, is equal to 82°. The ratio of the velocities is $\frac{2}{3}$, and let E be the force to be transmitted.

By operating in the way described above, we easily obtain the generatrix of contact A D. Upon this line we determine a point a, such that the perpendiculars as, at, let fall upon the axes, may be to each other as 2 is to 3. By taking $sb' = as$ and $tb = at$, we have the primitive diameters of the bases of the cones. Through the point a draw oo' perpendicular to A D; in this way we get two cones oab and $o'ab'$ which will limit the base of the gear. Having calculated the thickness of the teeth, and consequently the pitch, according to the force F in the manner described for spur-gear, take a length aa' varying between three and four times the thickness of a tooth, according to the nature of the metal employed and the conditions in which the pinions work.

Draw through the point a', $m\,n$ perpendicular to A D, and $a'\,c$, $a'\,c'$ parallel to $a\,b$ and $a'\,b'$, so that $a'\,k = k\,c$, and $a'\,h = h\,c'$; draw $m\,c$ and $n\,c'$. We get in this way two cones $m\,a\,c$ and $n\,a\,c'$, which



3157.

limit the upper portions of the pinions. The two lines which join A to the points b and b' evidently pass through the points c and c', and are the primitive generatrices or the several positions of the generatrix of contact.

Now, from the points o and o', with o o and o' o as radii, describe two arcs $a\,x$ and o x', which may be considered as the pitch-circles of two spur-wheels, and upon which the gear is constructed, with the pitch previously determined. The teeth thus obtained represent the bases of the teeth of the pinions. If we consider the teeth obtained for the wheel A C, the circumferences which limit them at their extremities and at their roots, meet the line $o\,o'$ in the points p and q; through these points draw lines parallel to o b' till they meet $o'\,b'$ in p and q'.

Now, with m o and n o' as radii transferred to m' o'' and n' o'', describe two arcs which will serve as a basis to a drawing analogous to the one given above. The teeth obtained form the upper extremities of those of the pinion. By bringing, through lines parallel to the generatrix of contact, the extremities and roots of the teeth upon $m\,n$, we get the points f and g, through which we draw lines parallel to $a'\,c$ and $a'\,c'$. We might determine these parallels equally well by giving the points p', q', to the summit A, which would give the points f', g'. The outline of the pinion is thus complete. What we have said is sufficient for practice, the rest belongs to descriptive geometry; we will, however, point out in summary manner what remains to be done to complete the plan.

Take a plane P Q perpendicular to the axis A C; mark upon this plane the different radii which have one of their extremities upon the axis and the other in the points p, a, q, and f, o', g; from the point v, with these radii, describe circles which will represent the plane of the pinion, projected at first upon the plane P Q. Upon the circumferences v o_1 and $v\,a'$, considered as pitch-circles, trace the teeth in the manner shown for spur-gear, that is, recommence the operations indicated by the dotted lines; then join the extremities of the teeth and project each of them upon the vertical plane. All the operations indicated for the wheel A C must be repeated for the other.

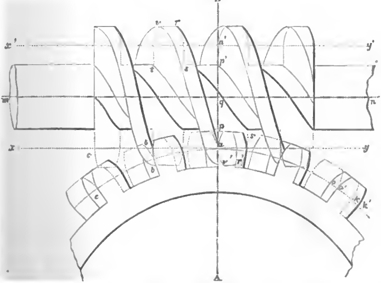
After having determined the generatrix of contact and the primitive radii of the wheels, it almost always happens that the pitch, determined in accordance with the force F, does not exactly divide the circumferences described with these radii. In this case the number of the teeth must be lessened, and consequently the pitch increased, until the division can be exactly made. No inconvenience can result from modifying in this direction the dimensions of the teeth.

We have selected as our example the case of two shafts forming an acute angle: the method of drawing is the same in all cases; but the most general case is that of two shafts placed at right angles to each other.

Endless Screw and Pinion.—When it is required to communicate the continuous circular motion of a shaft to another not situate in the same plane, the endless screw and pinion may be employed, if the given axes are at right angles and near each other.

The discussion of the principles upon which the construction of this gear rests would lead us into a somewhat complicated theory, which we will pass by for the sake of considering the drawing from a practical point of view. The data are reduced to the work and, consequently, to the force F to be transmitted.

3158.



It is generally required to obtain one revolution of the pinion to a determinate number of revolutions of the screw. In this case, the number of teeth on the pinion is equal to the number of revolutions of the screw. But the distance of the teeth is calculated for the force to be transmitted and remains invariable; therefore it is necessary to make the radius of the pinion depend upon the number of teeth; this cannot be, however, unless the distance of the axes be unlimited. It must be remarked that in almost all cases, the screw drives the pinion, the object being an increase of force at the cost of speed.

Knowing the maximum work to be transmitted, we may determine the pitch of the pinion, which is also that of the endless screw. The radius of the solid portion of the screw may be taken as a function of the pitch, since it is also dependent on the force. It is usually obtained by multiplying the pitch by 5, and dividing the result by 2. To execute the trace we must take A *a*, Fig. 3158, equal to the primitive radius of the pinion; draw through the point *a*, a perpendicular *x y*, which will be the pitch-line of the screw. From the point *a*, take upon the radius of the pinion produced, a length *a q* equal to $\frac{11}{15}$ the radius of the solid or central portion of the screw, so that *a p* may be equal to $\frac{4}{15}$ of this radius. By taking $q\,a' = q\,a$, and drawing $x'\,y'$ parallel to the axis *m n* and to *x y*, we obtain the other pitch-line of the screw.

Now mark upon the pitch-circle of the pinion the lengths *a b*, *b c* . . . , equal to the pitch; mark these same divisions upon *x y* in $a\,b'$, $b'\,c'$ . . . , and construct the teeth of a rack, by taking as their faces the cycloid generated by a circle of a diameter A *a*, rolling upon *x y*. Trace upon $x'\,y'$ teeth symmetrical to the preceding with respect to *m n*. The helicoidal portions which unite the profiles *r s* and *v t*, for example, to $r'\,s'$ and $p\,v'$, determine the thread and its inclination with respect to the axis of the screw.

The teeth of the pinion must have upon the disc which carries them the same inclination as the thread of the screw; the profile of them will therefore need to be traced upon each face of the wheel. Thus *o k* represents the profile of a tooth upon one face, and $o'\,k'$ the same profile upon the other; $o\,o'$ is therefore the inclination upon the breadth of the wheel. As to the form of this profile it has not been exactly determined, but if the teeth are large, they must be cut to receive as nearly as possible the impress of the thread of the screw. Besides this, the extremities of the teeth and the bottom of the spaces, instead of being straight, that is form of generatrices situate in planes parallel to the axis, will present circular gorges, the radii of which are a little greater than *p q* and *a q*.

It often happens that the endless screw has several threads; the distances which separate them are, in this case, equal fractions of their common pitch. The length of the screw may be limited to the three or four threads which act simultaneously. If we trace upon a cylinder of a considerable diameter, a series of threads of a very wide pitch, and then reduce each of them to a small portion of a spiral by means of two planes perpendicular to the axis and near together, we obtain what is called a helicoidal gear.

Construction of Cams for Stamps and Hammers.—The conversion of the continuous rotatory motion of a shaft into a reciprocating rotatory or rectilineal motion is frequently made in mills, and especially in iron-works, to obtain the ascensional motion of the stamps and hammers.

Suppose a rod A, Fig. 3159, furnished with a stamp, to be guided in such a way that it can move only in a vertical direction; such a rod may be raised by teeth or cams turning about an axis *o* and acting against a projecting part C. The stamp falls by its own weight, to be raised again by another cam.

When a system of this kind is established it is necessary to consider—1. The number *m* of cams to be employed. 2. The angular velocity of the shaft, or the number *n* of revolutions it is to make a minute. 3. The height to which the stamp is to be raised. 4. The radius of the pitch-circle to be developed to obtain the profile of the cams.

The course or stroke of the stamp is generally determined beforehand, and upon it alone depends the velocity of impact. The number of cams and the number of revolutions are mutually dependent, and their product *m n* must be equal to the number of strokes a minute. We must in all cases take one of the factors and deduce the value of the other.

If we denote by T the time of one revolution, the time which elapses between the beginning of two consecutive strokes will be expressed by $\frac{T}{m}$.

The number of strokes a minute being equal to *m n*, we have $\frac{T}{m} = \frac{60''}{m\,n}$.

As there are always some passive resistances opposed to the descent of the stamp, $\frac{T}{m}$ must be increased in value by $\frac{1}{6}$ or $\frac{1}{7}$ to prevent the stamp from falling upon the cam which is to raise it. This result may be arrived at by increasing the radius of the pitch-circle upon which we operate for the construction of cams.

Thus the time of one ascent is given by $\frac{6}{7}\,\frac{T}{m}$. The formula of the time occupied in the descent is $t^2 = \frac{2\,c}{g}$, or $t^2 = \frac{2\,h}{g}$, from which we deduce $t = \sqrt{\frac{2\,h}{9{\cdot}81}}$.

The time t' during which the cam will act upon the stamp is therefore expressed by

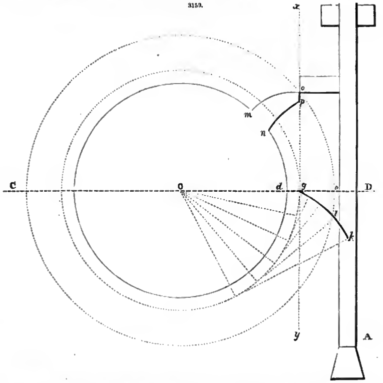
$$t' = \frac{6}{7}\,\frac{T}{m} - \sqrt{\frac{2\,h}{9{\cdot}81}}.$$

The radius of the circumference to be developed will now be calculated by the formula

$$r = \frac{60\,h}{t' \times 6{\cdot}28\,n}.$$

This radius may never be less than the value given by the formula, but no inconvenience can result from making it greater; this, indeed, is nearly always done.

3159.



Trace of Cams.—Having described a circle with a radius r, draw the vertical tangent $x\,y$ upon which the point of application of the force transmitted will constantly be. Take $g\,c = h$, and draw the highest position of the projecting piece c. Determine a portion $g\,k$ of the involute of the circle $o\,g$, and from the point o, with the radius $o\,c$, describe a circle, which will limit at the point l the length of the cam. The other face of the cam is generally a nearly straight line; it is traced so that the form obtained may be nearly that of a solid of equal resistance, the greatest thickness $m\,n$ of which is calculated according to the maximum force to be developed, and the strength of the materials.

Theoretically, the cam should possess no thickness at its extremity, but in practice it has a thickness, which, instead of being marked by the circumference passing by the point c, is marked by a portion $c\,p$ of the line $x\,y$. This allows the instantaneous escape of the stud c.

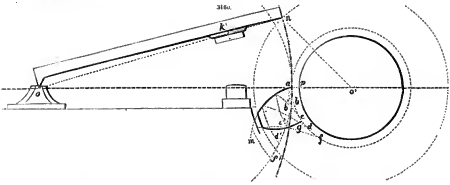
Epicycloidal Cams for converting a Continuous into a Reciprocating Rotatory Motion.—The construction of cams for raising mill-hammers differs from the preceding in using the epicycloid.

Let $o\,n$, Fig. 3160, be the whole length of the hammer; from the point o, about which the hammer revolves, describe a circle with the radius $o\,n$. Take as the radius of the pitch-circle of the cams a sufficient length to prevent the hammer from falling upon the cam which is to raise it. What we have said above in reference to this subject is equally applicable here.

To find the form to be given to the profile of the cams, describe a circle with the diameter $o\,a$, and determine a portion $a\,m$ of the epicycloid generated by the point a while this circle is rolling upon the circle $o'\,a$.

To find the limit of the cams, take from the point a, upon the circle with a radius $o\,a$, the arc $a\,n$, representing the space traversed by the end of the hammer in its ascent, and describe the circle with a radius $o'\,n$. The two profiles of the cam, as in the preceding case, need not be symmetrical, but generally they are made similar. The thickness $p\,q$ is determined in the manner described above for stamps. It may be remarked, however, that the resistance to be overcome by the cams is not in this case merely the whole weight of the hammer, and that the length of the arms of the lever turning about the point o must be taken into account. Neglecting the weight of the beam $o\,n$, and denoting the weight of the hammer by W, and the force borne by the cam by F, we have $F = \frac{OK \times W}{o\,n}$.

3160.

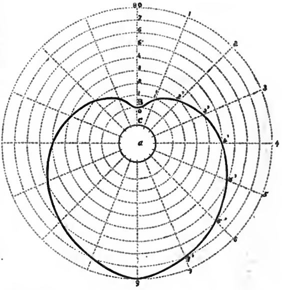


Suppose, as it is always well to suppose, that the load is constantly borne by the end of the cam, and denote by a, b, c, the three dimensions of the latter, that is, thickness in the direction of the force, breadth taken perpendicularly to the direction of this force, and the length of the cam. Neglecting the weight of the tooth, the section at the base will be given by the formula $a\,b^2 = \frac{F\,c}{1250000}$, if the cams are of cast iron. If they are of wrought iron, the divisor of the product $F\,c$ is 1000000; and if they are of wood, this divisor will be reduced to 100000.

Construction of the Heart-shaped Cam.—This cam, whose form is sufficiently indicated by its name, is used to convert the continuous rotatory motion of a shaft into a reciprocating rectilinear motion of a rod, and so on. The only datum necessary to the construction is the length of the stroke required.

To construct the heart-shaped eccentric, take a length A B, Fig. 3161, equal to the stroke; produce it first to C, B C being equal to the least thickness of metal to be retained about the shaft; then to a, C a being equal to the radius of the shaft. Describe the circles a C, a B, a A; divide each half of the circle A a into eight equal parts, for example; the greater the number, the more exact will be the construction. Draw the radii a 1, a 2, a 3 . . .; divide in like manner A B into eight equal parts, and from the centre a describe the circles passing through the points of division; the point in which each of these circles meets the radius of the same number is a point in the curve.

3161.



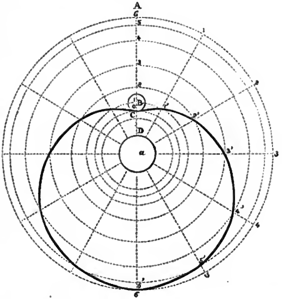
If the cam is to work against a roller, which is generally the case, the angle B must be rounded a little to give it the form of the roller; and a length equal to the radius of this roller added to the radius A a, which length is placed between the stroke A B and the thickness B C.

The heart-shaped cam possesses several valuable properties.

1. It intercepts upon all the lines passing through the centre a equal length; this enables it to turn in a frame.

2. The spaces traversed in a straight line by the frame or rod are exactly proportional to the angular velocity of the cam; whence it follows that if the rotatory motion of the shaft is uniform, the rectilinear motion produced is uniform also.

3162.



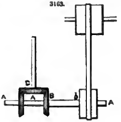
Trace of a Cam converting a Continuous Rotatory Motion into a Uniformly Periodical Motion.—Suppose the rectilinear motion to be produced to be slow at the beginning, accelerated during a certain time, and retarded towards the end of the stroke, so as to end with the velocity with which it began.

Having taken, as before, A B equal to the stroke, Fig. 3162, we add B C equal to the radius of the roller; the point C is here the beginning of the curve. Take C D as the least thickness of the metal and D a equal to the radius of the shaft. From the point C divide C A into parts proportional to the acceleration or the retardment of the velocity at the given points of the stroke, and describe from the centre a the circles passing through the points 1, 2, 3 . . . Divide each half of the circle a A into six equal parts, and draw the radii to the points of division; their intersection with the circumferences passing through the corresponding points of the stroke A C gives the points of the curve sought.

This eccentric cannot, like the last, work in a frame.

Fig. 3163. A method of engaging, disengaging, and reversing the upright shaft at the left. The belt is shown on the middle one of the three pulleys on the lower shafts a, b, which pulley is loose, and consequently no movement is communicated to the said shafts. When the belt is traversed on the left-hand pulley, which is fast on the hollow shaft b, carrying the bevel-gear B, motion is communicated in one direction to the upright shaft; and on its being traversed on to the right-hand pulley, motion is transmitted through the gear A, fast on the shaft a, which runs inside of b, and the direction of the upright shaft is reversed.

3163.



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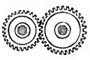

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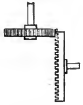
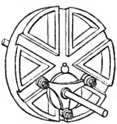


Fig. 3164. Spur-gears.

Fig. 3165. The wheel to the right is termed a *crown-wheel*; that gearing with it is a spur-gear. These wheels are not much used, and are only available for light work, as the teeth of the crown-wheel must necessarily be thin.

3166.



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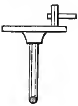

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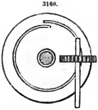

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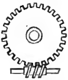

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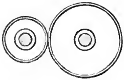

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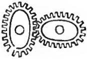

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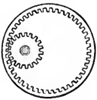

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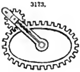

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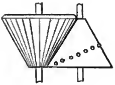

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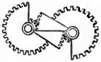

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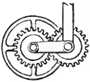

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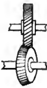

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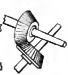

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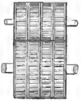

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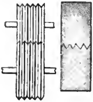

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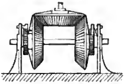

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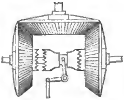

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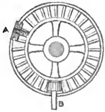

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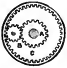

Fig. 3166. *Multiple-gearing*—a recent invention. The smaller triangular wheel drives the larger one by the movement of its attached friction-rollers in the radial grooves.

Fig. 3167. These are sometimes called brush-wheels. The relative speeds can be varied by changing the distance of the upper wheel from the centre of the lower one. The one drives the other by the friction or adhesion, and this may be increased by facing the lower one with india-rubber.

Fig. 3168. Transmission of rotary motion from one shaft at right angles to another. The spiral thread of the disc-wheel drives the spur-gear, moving it the distance of one tooth at every revolution.

Fig. 3169. Worm or endless screw and a worm-wheel. This effects the same result as Fig. 3168; and as it is more easily constructed, it is oftener used.

Fig. 3170. Friction-wheels. The surfaces of these wheels are made rough, so as to *bite* as much as possible; one is sometimes faced with leather, or, better, with vulcanized india-rubber.

Fig. 3171. Elliptical spur-gears. These are used where a rotary motion of varying speed is required, and the variation of speed is determined by the relation between the lengths of the major and minor axes of the ellipses.

Fig. 3172. An internally-toothed spur-gear and pinion. With ordinary spur-gears (such as represented in Fig. 3164) the direction of rotation is opposite; but with the internally-toothed gear, the two rotate in the same direction; and with the same strength of tooth the gears are capable of transmitting greater force, because more teeth are engaged.

Fig. 3173. Variable rotary motion produced by uniform rotary motion. The small spur-pinion works in a slot cut in the bar, which turns loosely upon the shaft of the elliptical gear. The bearing of the pinion-shaft has applied to it a spring, which keeps it engaged; the slot in the bar is to allow for the variation of length of radius of the elliptical gear.

Fig. 3174. Uniform into variable rotary motion. The bevel-wheel or pinion to the left has teeth cut through the whole width of its face. Its teeth work with a spirally-arranged series of studs on a conical wheel.

Fig. 3175. A means of converting rotary motion, by which the speed is made uniform during a part, and varied during another part, of the revolution.

Fig. 3176. Sun-and-planet motion. The spur-gear to the right, called the planet-gear, is tied to the centre of the other, or sun-gear, by an arm which preserves a constant distance between their centres. This was used as a substitute for the crank in a steam-engine by James Watt, after the use of the crank had been patented by another party. Each revolution of the planet-gear, which is rigidly attached to the connecting rod, gives two to the sun-gear, which is keyed to the fly-wheel shaft.

Figs. 3177, 3178. Different kinds of gears for transmitting rotary motion from one shaft to another arranged obliquely thereto.

Fig. 3179. A kind of gearing used to transmit great force and give a continuous bearing to the teeth. Each wheel is composed of two, three, or more distinct spur-gears. The teeth, instead of being in line, are arranged in steps to give a continuous bearing. This system is sometimes used for driving screw-propellers, and sometimes, with a rack of similar character, to drive the beds of large iron-planing machines.

Fig. 3180. Frictional grooved gearing—a comparatively recent invention. The diagram to the right is an enlarged section, which can be more easily understood.

Fig. 3181. Alternate circular motion of the horizontal shaft produces a continuous rotary motion of the vertical shaft, by means of the ratchet-wheels secured to the bevel-gears, the ratchet-teeth of the two wheels being set opposite ways, and the pawls acting in opposite directions. The bevel-gears and ratchet-wheels are loose on the shaft, and the pawls attached to arms firmly secured on the shaft.

Fig. 3182. The vertical shaft is made to drive the horizontal one in either direction, as may be desired, by means of the double-clutch and bevel-gears. The gears on the horizontal shaft are loose, and are driven in opposite directions by the third gear; the double-clutch slides upon a key or feather fixed on the horizontal shaft, which is made to rotate either to the right or left, according to the side on which it is engaged.

Fig. 3183. Mangle or star-wheel, for producing an alternating rotary motion.

Fig. 3184. Different velocity given to two gears, A and C, on the same shaft, by the pinion D.

Fig. 3185. The small pulley at the top being the driver, the large, internally-toothed gear and the concentric gear within will be driven in opposite directions by the bands, and at the same time will impart motion to the intermediate pinion at the bottom, both around its own centre and also around the common centre of the two concentric gears.

Fig. 3186. Jumping or intermittent rotary motion, used for meters and revolution-counters. The drop and attached pawl, carried by a spring at the left, are lifted by pins in the disc at the right. Pins escape first from pawl, which drops into next space of the star-wheel. When pin escapes from drop, spring throws down suddenly the drop, the pin on which strikes the pawl, which, by its action on star-wheel, rapidly gives it a portion of a revolution. This is repeated as each pin passes.

Fig. 3187. Another arrangement of jumping motion. Motion is communicated to worm-gear B by worm or endless screw at the bottom, which is fixed upon the driving shaft. Upon the shaft carrying the worm-gear works another hollow shaft, on which is fixed cam A. A short piece of this hollow shaft is half cut away. A pin fixed in worm-gear shaft turns hollow shaft and cam, the spring which presses on cam holding hollow shaft back against the pin until it arrives a little farther than shown in the figure, when, the direction of the pressure being changed by the peculiar shape of cam, the latter falls down suddenly, independently of worm-wheel, and remains at rest till the pin overtakes it, when the same action is repeated.

Fig. 3188. The left-hand disc or wheel C is the driving wheel, upon which is fixed the tappet A.

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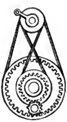

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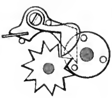

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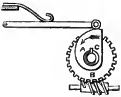

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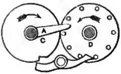

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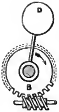

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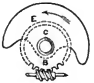

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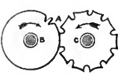

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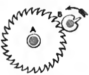

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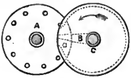

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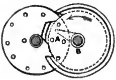

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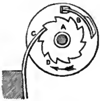

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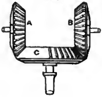

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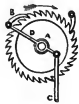

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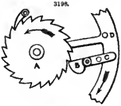

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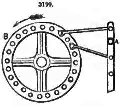

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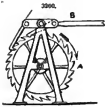

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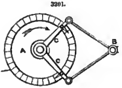

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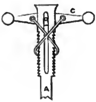

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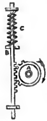

The other disc or wheel D has a series of equidistant studs projecting from its face. Every rotation of the tappet acting upon one of the studs in the wheel D causes the latter wheel to move the distance of one stud. In order that this may not be exceeded, a lever-like stop is arranged on a fixed centre. This stop operates in a notch cut in wheel C, and at the same instant tappet A strikes a stud, said notch faces the lever. As wheel D rotates the end between studs is thrust out, and the other extremity enters the notch; but immediately on the tappet leaving stud, the lever is again forced up in front of next stud, and is there held by periphery of C pressing on its other end.

. Fig. 3189. A modification of Fig. 3187; a weight D, attached to an arm secured in the shaft of the worm-gear, being used instead of spring and cam.

Fig. 3190. Another modification of Fig. 3187; a weight or tumbler E, secured on the hollow shaft, being used instead of spring and cam, and operating in combination with pin C, in the shaft of worm-gear.

Fig. 3191. The single tooth A of the driving wheel B acts in the notches of the wheel C, and turns the latter the distance of one notch in every revolution of C. No stop is necessary in this movement, as the driving wheel B serves as a lock by fitting into the hollows cut in the circumference of the wheel C between its notches.

Fig. 3192. B, a small wheel with one tooth, is the driver, and the circumference entering between the teeth of the wheel A, serves as a lock or stop while the tooth of the small wheel is out of operation.

Fig. 3193. The driving wheel C has a *rim*, shown in dotted outline, the exterior of which serves as a bearing and stop for the studs on the other wheel A, when the tappet B is out of contact with the studs. An opening in this rim serves to allow one stud to pass in and another to pass out. The tappet is opposite the middle of this opening.

Fig. 3194. The inner circumference (shown by dotted lines) of the rim of the driving wheel B serves as a lock against which two of the studs in the wheel C rest until the tappet A, striking one of the studs, the next one below passes out from the guard-rim through the lower notch, and another stud enters the rim through the upper notch.

Fig. 3195. To the driving wheel D is secured a bent spring B; another spring C is attached to a fixed support. As the wheel D revolves, the spring B passes under the strong spring C, which presses it into a tooth of the ratchet-wheel A, which is thus made to rotate. The catch-spring B, being released on its escape from the strong spring C, allows the wheel A to remain at rest till D has made another revolution. The spring C serves as a stop.

Fig. 3196. A uniform intermittent rotary motion in opposite directions is given to the bevel-gears A and B by means of the mutilated bevel-gear C.

Fig. 3197. Reciprocating rectilinear motion of the rod C transmits an intermittent circular motion to the wheel A, by means of the pawl B at the end of the vibrating bar D.

Fig. 3198 is another contrivance for registering or counting revolutions. A tappet B, supported on the fixed pivot C, is struck at every revolution of the large wheel (partly represented) by a stud D attached to the said wheel. This causes the end of the tappet next the ratchet-wheel A to be lifted, and to turn the wheel the distance of one tooth. The tappet returns by its own weight to its original position after the stud D has passed, the end being jointed to permit it to pass the teeth of the ratchet-wheel.

Fig. 3199. The vibration of the lever C on the centre or fulcrum A produces a rotary movement of the wheel B, by means of the two pawls, which act alternately. This is almost a continuous movement.

Fig. 3200. A modification of Fig. 3199.

Fig. 3201. Reciprocating rectilinear motion of the rod B produces a nearly continuous rotary movement of the ratchet-faced wheel A, by the pawls attached to the extremities of the vibrating radial arms C C.

Fig. 3202. Rectilinear motion is imparted to the slotted bar A by the vibration of the lever C through the agency of the two hooked pawls, which drop alternately into the teeth of the slotted rack-bar A.

Fig. 3203. Alternate rectilinear motion is given to the rack-rod B by the continuous revolution of the mutilated spur-gear A, the spiral spring C forcing the rod back to its original position on the teeth of the gear A quitting the rack.

Fig. 3204. On motion being given to the two treadles D a nearly continuous motion is imparted, through the vibrating arms B and their attached pawls, to the ratchet-wheel A. A chain or strap attached to each treadle passes over the pulley C, and as one treadle is depressed the other is raised.

Fig. 3205. A nearly continuous rotary motion is given to the wheel D by two ratchet-toothed arcs C, one operating on each side of the ratchet-wheel D. These arcs (only one of which is shown) are fast on the same rock-shaft B, and have their teeth set opposite ways. The rock-shaft is worked by giving a reciprocating rectilinear motion to the rod A. The arcs should have springs applied to them, so that each may be capable of rising to allow its teeth to slide over those of the wheel in moving one way.

Fig. 3206. The double rack-frame B is suspended from the rod A. Continuous rotary motion is given to the cam D. When the shaft of the cam is midway between the two racks, the cam acts upon neither of them; but by raising or lowering the rod A either the lower or upper rack is brought within range of the cam, and the rack-frame moved to the left or right. This movement has been used in connection with the governor of an engine, the rod A being connected with the governor, and the rack-frame with the throttle or regulating valve.

Fig. 3207. Uniform circular motion into reciprocating rectilinear motion, by means of mutilated pinion, which drives alternately the top and bottom rack.

Fig. 3208. Circular motion into alternate rectilinear motion. Motion is transmitted through pulley at the left upon the worm-shaft. Worm slides upon shaft, but is made to turn with it by

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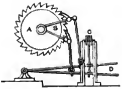

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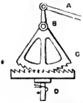

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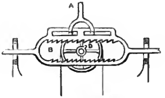

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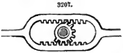

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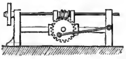

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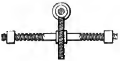

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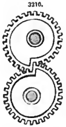

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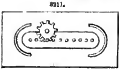

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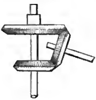

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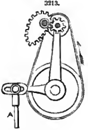

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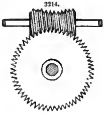

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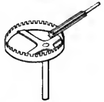

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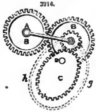

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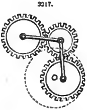

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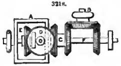

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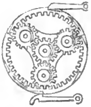

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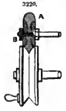

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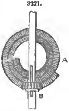

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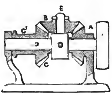


means of a groove cut in shaft, and a key in hub of worm. Worm is carried by a small traversing frame, which slides upon a horizontal bar of the fixed frame, and the traversing frame also carries the toothed wheel into which the worm gears. One end of a connecting rod is attached to fixed frame at the right and the other end to a wrist secured in toothed wheel. On turning worm-shaft rotary motion is transmitted by worm to wheel, which, as it revolves, is forced by connecting rod to make an alternating traverse motion.

Fig. 3209. Continuous circular into continuous but much slower rectilinear motion. The worm on the upper shaft, acting on the toothed wheel on the screw-shaft, causes the right and left hand screw-threads to move the nuts upon them toward or from each other according to the direction of rotation.

Fig. 3210. Scroll-gears for obtaining a gradually-increasing speed.

Fig. 3211. What is called a *mangle-rack*. A continuous rotation of the pinion will give a reciprocating motion to the square frame. The pinion-shaft must be free to rise and fall, to pass round the guides at the ends of the rack. This motion may be modified as follows;—If the square frame be fixed, and the pinion be fixed upon a shaft made with a universal joint, the end of the shaft will describe a line, similar to that shown in the drawing, around the rack.

Fig. 3212. A mode of obtaining two different speeds on the same shaft from one driving wheel.

Fig. 3213. A continual rotation of the pinion (obtained through the irregular-shaped gear at the left) gives a variable vibrating movement to the horizontal arm, and a variable reciprocating movement to the rod A.

Fig. 3214. Worm or endless screw and worm-wheel. Used when steadiness or great power is required.

Fig. 3215. Variable circular motion by crown-wheel and pinion. The crown-wheel is placed eccentrically to the shaft, therefore the relative radius changes.

Fig. 3216. Irregular circular motion imparted to wheel A. C is an elliptical spur-gear rotating round centre D, and is the driver. B is a small pinion with teeth of the same pitch, gearing with C. The centre of this pinion is not fixed, but is carried by an arm or frame which vibrates on a centre A, so that as C revolves the frame rises and falls to enable pinion to remain in gear with it, notwithstanding the variation in its radius of contact. To keep the teeth of C and B in gear to a proper depth, and prevent them from riding over each other, wheel C has attached to it a plate which extends beyond it and is furnished with a groove *g h* of similar elliptical form, for the reception of a pin or small roller attached to the vibrating arm concentric with pinion B.

Fig. 3217. If for the eccentric wheel described in the last figure an ordinary spur-gear moving on an eccentric centre of motion be substituted, a simple link connecting the centre of the wheel with that of the pinion with which it gears will maintain proper pitching of teeth in a more simple manner than the groove.

Fig. 3218. This movement is designed to double the speed by gears of equal diameters and numbers of teeth—a result once generally supposed to be impossible. Six bevel-gears are employed. The gear on the shaft B is in gear with two others—one on the shaft F, and the other on the same hollow shaft with C, which turns loosely on F. The gear D is carried by the frame A, which, being fast on the shaft F, is made to rotate, and therefore takes round D with it. E is loose on the shaft F, and gears with D. Now, suppose the two gears on the hollow shaft C were removed and D prevented from turning on its axis, one revolution given to the gear on B would cause the frame A also to receive one revolution, and as this frame carries with it the gear D, gearing with E, one revolution would be imparted to E; but if the gears on the hollow shaft C were replaced D would receive also a revolution on its axis during the one revolution of B, and thus would produce two revolutions of E.

Fig. 3219. Wheel-work in the base of capstan. Thus provided, the capstan can be used as a simple or compound machine, single or triple purchase. The drumhead and barrel rotate independently; the former, being fixed on spindle, turns it round, and when locked to barrel turns it also, forming single purchase; but when unlocked wheel-work acts, and drumhead and barrel rotate in opposite directions, with velocities as three to one.

Fig. 3220. J. W. Howlett's adjustable frictional gearing. This is an improvement on that shown in Fig. 3180. The upper wheel A shown in section, is composed of a rubber disc with V-edge, clamped between two metal plates. By screwing up the nut B, which holds the parts together, the rubber disc is made to expand radially, and greater tractive power may be produced between the two wheels.

Fig. 3221. Scroll-gear and sliding pinion, to produce an increasing velocity of scroll-plate A, in one direction, and a decreasing velocity when the motion is reversed. Pinion B moves on a feather on the shaft.

Fig. 3222. Entwistle's gearing. Bevel-gear A is fixed. B, gearing with A, is fitted to rotate on stud E, secured to shaft D, and it also gears with bevel-gear C loose, on the shaft D. On rotary motion being given to shaft D, the gear E revolves around A, and also rotates upon its own axis, and so acts upon C in two ways, namely, by its rotation on its own axis and by its revolution around A. With three gears of equal size, the gear C makes two revolutions for every one of the shaft D. This velocity of revolution may, however, be varied by changing the relative sizes of the gears. C is represented with an attached drum C′. This gearing may be used for steering apparatus, driving screw-propellers, &c. By applying power to C action may be reversed, and a slow motion of D obtained.

GEODESY. Fr., *Géodésie*; Ger., *Geodäsie*; Ital., *Geodesia*; Span., *Geodesia*.

An extensive survey made over large portions of the surface of the earth, either for the purpose of ascertaining the exact position of the principal places of a country, or of determining the dimensions and figure of the earth, is usually designated a Trigonometrical survey. This branch of surveying is termed *Geodesy*.

For this purpose a country is first divided into a number of large triangles, whose sides are usually from 10 to 20 miles in length; but sometimes they extend to 50 or 60 miles, and even occasionally, as in Spain and the west of Scotland, to 100 miles in length. All the angles of the triangles are then carefully observed, and a line situated in a level tract of country, called a *base line*, is measured with extreme care. These triangles may be said to form a species of polyhedron, circumscribing a portion of the earth, and they are reduced to others on its surface at the level of the sea, by supposing perpendiculars to be drawn from each station to the surface. The latitudes and longitudes of the different stations are then determined; and also their heights, and the angles which the sides of the triangle make with the meridional line.

The great triangles, into which the country is divided in the first instance, are denominated *principal* triangles. They are afterwards, by a second series of operations, subdivided into smaller ones, called *secondary* triangles, and these again are broken up into others of still smaller dimensions, until at length a survey of the whole country is made of any degree of minuteness which may be thought necessary. The calculations are finally *verified* by measuring other base lines, and comparing them with their lengths determined by calculation.

In the choice of stations, in a trigonometrical survey, there are two points which ought principally to be attended to;—1st. The angles should have such a magnitude, that any small inevitable errors in the observations shall produce the least effect on the sides to be calculated. 2nd. The stations should all be distinctly visible from each other.

To determine the most advantageous conditions of a Triangle.—Let a, b, c, be the sides of a triangle, and A, B, C, the angles respectively opposite to them. The angles are all known from observation, and the side a is either measured or determined from previous calculation. The side b is then found from the equation

$$b \sin. A = a \sin. B. \qquad [a]$$

Suppose now that the side a is accurately known, but that the angles A and B have not been correctly measured. Let α, β, be the respective errors in A and B, and let x be the corresponding error in the side b. We have then $(b + x) \sin. (A + \alpha) = a \sin. (B + \beta)$.

Expanding this expression, and putting $\cos. \alpha = 1$, $\sin. \alpha = \alpha$, $\cos. \beta = 1$, $\sin. \beta = \beta$, since the errors α, β, are necessarily very small, we get

$$(b + x) (\sin. A + \alpha \cos. A) = a (\sin. B + \beta \cos. B).$$

Subtracting $[a]$ from this equation, and omitting the term $x \alpha \cos. A$, which is the second order, and extremely small compared with the other terms, we get

$$x \sin. A + b \alpha \cos. A = a \beta \cos. B = \frac{b \sin. A}{\sin. B} \beta \cos. B;$$

$$\therefore \quad x = b (\beta \cot. B - \alpha \cot. A). \qquad [1]$$

Hence, if we suppose the errors α and β to be equal, and to have the same sign, the error x will be 0 when $A = B$; that is, there will be no error in calculating the side b, although the angles A and B are not correctly observed. If the errors α and β are equal, but have different signs, this equation becomes $x = b \alpha (\cot. A + \cot. B)$.

Now, $$\cot. A + \cot. B = \frac{\cos. A}{\sin. A} + \frac{\cos. B}{\sin. B} = \frac{(\sin. A + B)}{\sin. A \sin. B}.$$

Also,

$$2 \sin. A \sin. B = \cos. (A - B) - \cos. (A + B) = \cos. (A - B) + \cos. C, \text{ and } \sin. (A + B) = \sin. C,$$

therefore $$x = b \alpha \frac{2 \sin. C}{\cos. (A - B) + \cos. C}, \qquad [2]$$

an expression which is evidently the least possible when $A = B$.

Since the same reasoning is applicable to the third side c, it follows that the most advantageous conditions of a triangle are *that its sides should be as nearly equal as possible*. But, as it is frequently impossible to fulfil these conditions, surveyors are in general satisfied with rejecting all triangles which have an angle less than 30°.

If the angles are accurately known, but there is an error in the side a, it is evident that the errors in the sides b and c will be proportional to their lengths; for the angles being constant the triangles will be similar. Hence it is of the utmost importance to measure the base line correctly, for any error in this line, which is necessarily very short compared with the extent of the country to be surveyed, will be continued through the whole chain of triangles, and magnified in proportion to the length of the sides.

Description of Signals.—All the stations should be situated in the most elevated part of the country, so as to be seen from each other without difficulty. In many cases the theodolite has to be elevated to the top of some tower, church-steeple, or other building, and flagstaffs placed over the instruments. These can be more easily distinguished when their figures are seen in the sky, than when they are projected on the earth or on trees. For more distant stations, *Bengal* or *white lights* were at first used by General Roy. Afterwards the reflection of the sun from a plane mirror, as recommended by Gauss, was employed by Colonel Colby and Captain Kater, in verifying that part of General Roy's triangulation which connected the meridians of Greenwich and Paris. *Drummond lights* were used as night signals at some of the stations in Ireland and the west of Scotland; but the practice of observing by night has lately been abandoned, in consequence of the unsteadiness of the light and the quantity of vapour in the atmosphere. Signals in the English survey were sometimes formed by building a temporary shed in the form of the frustum of a cone, over the point which marks the centre of the station. When the distances are not very great a plate of metal is sometimes used, with a narrow vertical slit cut in it; in which case the line of light passing through it may be seen very distinctly.

In elevating a signal for the purposes of observation, it is necessary that it should be sufficiently high to be easily distinguished from the surrounding objects. From the experience of the French surveyors, they state that the angle of elevation should be at least 31″; and as tan. 31″ = 0·00015, it follows that the height of the signal must be equal to 0·00015 × distance. In practice, therefore, the French usually made the height of the signal equal to a seven thousandth part of the distance from whence it was to be observed, and the base of the signal equal to half its height. Hence if the distance be 20 miles, a distance not unusual in the trigonometrical survey, the signal should be at least 15 ft in height.

Of all the operations in which the surveyor is engaged, that which appears the most simple, but which is by far the most difficult, is the measurement of a base line. Since this line is seldom more than six or seven miles in length, and any error in its measurement is multiplied in the other parts of the survey in proportion to their linear dimensions, it is obvious that, in a tract of country 300 miles long, the error in this length would be fifty times the error in the base line. Every precaution, therefore, has been taken which art or ingenuity could devise to ensure the greatest accuracy in this most important operation.

The first thing to be done is to select a level piece of ground, from five to seven or eight miles in length, which shall be free from local obstructions, and commodiously situated with respect to surrounding objects. It is also desirable that it should not be far distant from an observatory, so that the whole chain of triangles may be connected with a fixed station, where astronomical observations are made with the utmost care and precision.

After the ground has been selected, a line is drawn in the same vertical plane, by means of a transit telescope, and marked out by pickets, the tops of which are brought exactly into the same level. The tract which is to be measured is then cleared of all obstructions, and made tolerably smooth; and the extremities of the base are permanently fixed by dots marked on cannon, or on massive blocks of stone.

Deal Rods.—In the commencement of the English survey, General Roy made use of deal rods, 20 ft. 3 in. long, about 2 in. deep, and 1¼ in. broad, on which lengths of 20 ft. were laid off by Ramsden. They were constructed in such a manner that they might be used either by butting the end of one rod against the end of another, or by bringing fine transverse lines, inlaid into the upper surface at the distance of 1½ in. from each extremity, into exact coincidence; but the method of coincidences was attended with so much inconvenience and loss of time, that General Roy was compelled to abandon it, and to proceed solely by the method of contacts. Notwithstanding all the care, however, that was taken to select rods of the best materials, they were found liable to such irregular and sudden variations of length, from the moisture of the atmosphere, that they were entirely abandoned, after the first base on Hounslow Heath had been completed. The error in this measurement was found to be about 21 in.

Glass Rods.—When it was discovered that the deal rods would not prove satisfactory, it was proposed that glass rods should be substituted in their place. Tubes were used rather than solid rods, as it was found that a sufficient quantity of melted glass could not be taken on the irons which were used at the glass-house for drawing the rods. Three hollow tubes were, therefore, selected, and converted by Ramsden into measuring rods. They were then placed in cases, to which they were made fast in the middle, and also braced at two other points; the whole together serving as stays to keep the tubes in their true places from shaking, but not binding them too closely. The ends were ground perfectly smooth, and at right angles to the axis of the bore; one end having a fixed apparatus, or metal button, attached to it, for making the contacts, and the other end a movable apparatus or slider, which was pressed outwards by a slender spring. The fixed extremity of the succeeding rod was pushed against this spring until a fine line on the slider was brought into exact coincidence with another fine line on the glass rod, in which state the distance between the extremities was exactly 20 ft.

Steel Chains.—The third method of measuring a base line, by the English surveyors, was with a steel chain made by Ramsden. This chain was 100 ft. in length, and contained 40 links of 2½ ft. each. A transverse section of these links was a square, each of whose sides was ¼ an inch. In using the chain five coffers were arranged in a straight line, and supported either by trestles or courses of bricks; the chain was placed on the coffers and stretched with a constant weight of 56 lbs. The ends were brought over the same point in this manner;—At the extremity of the chain, but unconnected with it, and on a separate post, was placed a scale. When the chain was in any position, the scale at the preceding end was moved by means of screws, until one of its divisions coincided exactly with the mark on the handle of the chain. This scale remaining in its place, the chain was carried forward into its next position, and adjusted, by means of its screw apparatus, until the mark in its following end coincided exactly with that division of the scale which had been in coincidence with the mark on the preceding end.

	Feet.
The measurement of the base on Hounslow Heath, made with deal rods, reduced to the lowest extremity, was found to be	27406·26
„ with glass tubes	27404·0843
„ with steel chain	27404·3155

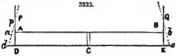
The mean of the two last results, or 27404·2 ft., was assumed as the true length of the base in the future calculations.

Notwithstanding the near agreement of the two last methods of measuring a base line, it has been objected to the glass rods;—1st. That some error might arise from the ends of the two consecutive rods being made to rest on the same trestle, because when the first rod was taken off, the face of the trestle being pressed by one rod only, would have a tendency to incline a little forward, the effects of which would be to shorten the apparent length of the base. 2nd. That some error might arise from the casual deviation of the rods from a straight line in the direction of the base. 3rd. That from the manner of supporting the rods on two trestles only, they would be liable to bend in the middle. To the steel chain it has also been objected, by Legendre and others, that, as the chain is not uniformly supported at every point, some doubt must remain whether it is perfectly straight when placed in the coffers, and also that its length is liable to vary from the rubbing and wear of the joints.

Rods of Platinum and Brass.—In the French surveys, rods of platinum were used. These were two toises, or 12 French feet, in length; their breadth was about six lines, or half a French inch, and their thickness one line. On the surface of the platinum was placed another rod of brass, firmly fixed at one end to the rod of platinum, by means of three screws, but entirely free at the other end, and throughout its whole length. It was about 6 in. shorter than the rod of platinum; and, from the different expansive powers of the two metals, the two rods united might be considered as a kind of metallic thermometer. Four rods were used in the measurement, three of which were always on the ground at the same time; and, in order to prevent any derangement from bringing the ends into contact, a small interval of about ⅓ of an inch was left between them, which was measured by means of a slider attached to the preceding end of each rod. The slider was then pushed gently out, until it came into contact with the following end of the next rod.

Colonel Colby's Method.—The last method adopted, in the survey of Ireland, is an ingenious apparatus made by Troughton, Fig. 3223, which supersedes all other instruments. A B is a bar of iron, 10 ft. long, 1½ in. deep, and ½ of an inch broad, united to a bar of brass D E, of the same dimensions, at the distance of 2 in. These bars are firmly riveted together at their centres, but are free to move at the extremities, according to their respective expansions. The base D E is covered with a non-conducting substance, to make the two bars equally susceptible of heat. P D, Q E, are two tongues of steel, attached to the rods by double conical joints, around which they are capable of turning and forming a small angle with the lines perpendicular to the bars. P and Q are two dots of platinum, so exceedingly minute as to be almost invisible to the naked eye. At the temperature of 60° the bars are exactly of the same length, and the tongues P D, Q E, are then perpendicular to the bars; but if the temperature be increased, the bars will expand in different proportions; thus, if P *a d*, Q *b c*, represent the position of the tongues at the temperature of 70°, and the expansion of iron be to that of brass as 53 to 83, then A *a* : D *d* :: P A : P D :: 53 : 83.

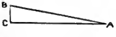
3223.



Hence the situation of the point P, about which the tongue P E revolves, is invariable, or at least is sensibly so in practice, for all moderate variations of temperature. The same thing is true with respect to the point Q, and consequently the distance P Q remains, in all moderate changes of temperature, of the exact length of 10 ft. It is evident, however, that this can only be true within certain limits; for, as P *d* is no longer equal to P D, the point P will have moved to *p*, nearer to *d*, making *p d* = P D; and the distance of *p* from P D is evidently equal to P D × (tan. D P *d* − sin. D P *d*). But as the angle D P *d* is, in practice, always extremely small, the difference between its tangent and its sine is altogether insensible.

In the Irish survey, five or six sets of bars, constructed in this manner, and placed in strong deal boxes, supported on trestles, were laid along the line to be measured, and accurately levelled. They were placed at a short distance from each other, and the distance between the dots on the adjacent steel tongues of two succeeding bars was accurately measured, by means of powerful micrometers, constructed so as to form a compensating instrument of the same nature as the measuring bars. It is stated that the greatest possible error of the base, measured on the eastern shore of Lough Foyle, cannot exceed 2 in., though the length is very nearly eight miles.

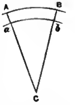
The Reduction of the Hypothenuses.—As the ground on which the base is measured is seldom perfectly level, the whole distance is divided into a number of inclined lines in the same vertical plane. Let A B be one of those lines, whose length is l, B C = h, the height of this plane, and the inclination of the plane B A C = θ. In the first English surveys, B C, the height of B above A, was found from levelling, and therefore the base A C = $\sqrt{(l^2 - h^2)}$. But in the latter surveys, as well as in those on the Continent, the angle θ was measured, and therefore the correction A B − A C is equal to $l\,(1 - \cos.\,\theta)$.



Correction of Temperature.—In the English survey, the temperature of the rods and chain was found from the mean of a number of thermometers; and the rate of expansion was previously determined by Ramsden. In the French survey, the measuring rod itself is the thermometer, and the difference of the rates of expansion between the platinum and the brass is carefully ascertained before the survey commences. In either case the correction is easily found by a single proportion, or by means of tables constructed for the purpose.

Reduction to the Level of the Sea.—Let A B, Fig. 3224, be the arc which has been measured, as described above, and corrected on account of temperature and the inclinations of the hypothenuses. This arc may be supposed to be taken at a mean between the heights of the two extreme points. Let $a\,b$ be a concentric arc at the level of the sea, and C a the radius of the earth. Put C $a = r$, A $a = h$, A B = L, $a\,b = l$, we have then C A : C a :: A B : $a\,b$;

3224.



$$\therefore \quad l = \mathrm{L}\,\frac{r}{r+h} = \left(1 - \frac{h}{r} + \frac{h^2}{r^2} - \&c.\right) = \mathrm{L} - \frac{\mathrm{L}\,h}{r}, \qquad [3]$$

nearly. In order, therefore, to reduce the base to the level of the sea, we must subtract the correction $\frac{L\,h}{r}$ from the length.

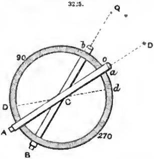
We will now give, as an example, the final result of the measurement of the first base, with glass rods, on Hounslow Heath. (Trig. Survey, vol. I., p. 87.)

	Feet.
Hypothenusal length of the base as measured by 1369·925521 glass rods, of 20 ft. each + 4·31 ft.	27402·8204
Reduction of the hypothenuses, to be subtracted	− 0·0714
Add the difference between the expansion of the glass above, and the contraction of it below, 62°	+ 0·3489
Add also for 6° difference of temperature of the standard brass scale and the glass rods	+ 0·9864
Length of the base, in temperature 62°	27404·0843
Reduction from the height of the lower end of the base above the mean level of the sea, supposed to be 54 ft...	− 0·0706
True length of the base, reduced to the mean level of the sea ..	27404·0137

The Measurement and Reduction of the Angles.—In all the surveys made in the British dominions, the instrument for measuring angles has been a large theodolite, rendered as perfect as the ingenuity of English artists could make it. This instrument may be defined to be an altitude and azimuth instrument, or an instrument for measuring vertical and horizontal angles. The horizontal circle was 3 ft. in diameter, and angles could be measured with it to the fractional part of a second.

The instrument used by the French and Swedish surveyors was the repeating circle of Borda. The principle of the circle of repetition is to take the angle several times successively in continuation on the circle, and then divide the whole arc by the number of observations.

3225.

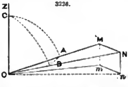


Let A B D, Fig. 3225, be a circle graduated entirely round the circumference from right to left on the upper side only of the instrument. A *a*, B *b*, are two telescopes, the one on the upper and the other on the under side of the instrument; these telescopes can either be moved independently or they may be clamped and moved altogether with the circle. Let P and Q be two objects whose angular distance is to be measured; and let the instrument by means of a stand be brought into the plane P C Q. Place the upper telescope A *a* at zero, and direct it to the object P; also direct the under telescope B *b* to the object Q. The two telescopes are then clamped, and the entire instrument is turned in its plane until B *b* be pointed to P. A *a* will now be in the position D *d*, making the angle *a* C *d* equal to *a* C *b*; unclamp it and turn it back to Q, while the circle itself remains fixed; it is evident that A *a* has moved through an angle *d* C *b*, equal to twice the required angle P C Q. The whole circle must now be turned again until A *a* points to P, then will B *b* be in the position D *d*; turn B *b* again through the angle *d* C *b* to Q and clamp it. As the under-side of the circle is not graduated, the angular distance of *b* from zero cannot be measured. Now move the whole circle until B *b* points to P, and turn A *a* again until it points to Q; the telescope A *a* will have been turned through four times the arc *a b*; and by repeating the process the arc can be multiplied any even number of times. It will readily be seen that the circle must always be turned to the *right* through the arc *b a*, and the two telescopes alternately to the *left* through *d b*, or twice the arc *a b*.

The advantages of this method are obvious. The errors of graduation may be diminished to any degree, and the errors of observation tend to destroy each other. The two circles which Delambre used were $0^{m}\cdot21$ and $0^{m}\cdot18$, or about 7 in. in diameter; and although the instruments were only graduated to minutes, yet by successively repeating the angle ten, twelve, or even as far as twenty times, he imagined that he could determine the angle within a second.

Various opinions have been entertained with respect to the relative merits of the theodolite and the repeating circle. The French have imagined that they could attain any degree of accuracy with the circle, and that all errors of division and errors of observation might be entirely annihilated by repetition.

3226.



When the angles are measured with a theodolite, no correction is required on account of the different altitudes of the signals, as it is the horizontal angle which is observed with the instrument; but when the sextant or repeating circle is employed, the oblique angles are observed, and these must be reduced to the plane of the horizon.

To reduce the oblique angles to the plane of the horizon.—Let O, Fig. 3226, be the place of the observer, M O N the angle observed between two signals M, N; M *m*, N *n*, two vertical lines meeting the horizontal plane *m* O *n* in the points *m*, *n*. Let O Z be a vertical line passing through O, and with the centre O and radius 1 conceive a sphere to be described, and let the planes Z O M, Z O N, M O N, cut this sphere in the great circles C A, C B, A B. The angle observed with the repeating circle is the oblique angle M O N, which is measured by the arc A B, but the required angle is m O n, which is equal to the spherical angle C. The angles M O m, N O n, are known from observation, and therefore the complements of these angles, or the arcs C A, C B, are known. We have then, in the triangle C A B, the three sides C A, C B, A B, given to find the angle C.

Let h, h', be the altitudes of the two signals M and N, θ the angle between them; also, let the horizontal angle $= \theta + x$; then $\mathrm{C\,A} = 90^\circ - h$, $\mathrm{C\,B} = 90^\circ - h'$, $\mathrm{A\,B} = \theta$, angle $\mathrm{C} = \theta + x$. By Trig., $\cos.\ \mathrm{C} = \dfrac{\cos.\ \mathrm{A\,B} - \cos.\ \mathrm{C\,A} \cos.\ \mathrm{C\,B}}{\sin.\ \mathrm{C\,A} \sin.\ \mathrm{C\,B}}$, or $\cos.\ (\theta + x) = \dfrac{\cos.\ \theta - \sin.\ h \sin.\ h'}{\cos.\ h \cos.\ h'}$.

Now, in practice, h, h', are very small, and $\theta + x$ is nearly equal to θ, therefore x also is very small. Hence $\cos.\ (\theta + x) = \cos.\ \theta \cos.\ x - \sin.\ \theta \sin.\ x = \cos.\ \theta - x \sin.\ \theta$, nearly.

Also, $\cos.\ h \cos.\ h' = (1 - \frac{1}{2} h^2 + \&c.)\,(1 - \frac{1}{2} h'^2 + \&c.) = 1 - \frac{1}{2}(h^2 + h'^2) + \&c.$

$$\therefore\ \frac{1}{\cos.\ h \cos.\ h'} = \frac{1}{1 - \frac{1}{2}(h^2 + h'^2) + \&c.} = 1 + \tfrac{1}{2}(h^2 + h'^2),\ \text{nearly, and}\ \sin.\ h \sin.\ h' = h\,h',$$

nearly. Substituting these values above, we have

$$\cos.\ \theta - x \sin.\ \theta = (\cos.\ \theta - h\,h') \left\{ 1 + \tfrac{1}{2}(h^2 + h'^2) \right\}.$$

$$\text{Hence}\quad x \sin.\ \theta = h\,h' - \tfrac{1}{2}(h^2 + h'^2) \cos.\ \theta = \frac{(h + h')^2 - (h - h')^2}{4} - \frac{(h + h')^2 + (h - h')^2}{4} \cos.\ \theta;$$

$$\therefore\ x = \frac{(h + h')^2}{4}\ \frac{1 - \cos.\ \theta}{\sin.\ \theta} - \frac{(h - h')^2}{4}\ \frac{1 + \cos.\ \theta}{\sin.\ \theta} = \tfrac{1}{4}(h + h')^2 \tan.\ \tfrac{1}{2}\theta - \tfrac{1}{4}(h - h')^2 \cot.\ \tfrac{1}{2}\theta.$$

Here x is measured in parts of the radius; if it be measured in seconds we have $x = x'' \sin.\ 1''$; therefore

$$x'' = \frac{(h + h')^2}{4}\ \frac{\tan.\ \frac{1}{2}\theta}{\sin.\ 1''} - \frac{(h - h')^2}{4}\ \frac{\cot.\ \frac{1}{2}\theta}{\sin.\ 1''}. \qquad [4]$$

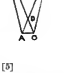
Example.—Let $\theta = 51^\circ\ 9'\ 29''{\cdot}774$, $h = 1^\circ\ 32'\ 45''$, $h' = 1^\circ\ 7'\ 10''$, then $\frac{1}{2}(h + h') = 4797''{\cdot}5$, $\frac{1}{2}(h - h') = 767''{\cdot}5$.

2 log. $\frac{1}{2}(h + h')$	7·362030	2 log. $\frac{1}{2}(h - h')$	5·770156
tan. $\frac{1}{2}\theta$	9·680038	cot. $\frac{1}{2}\theta$	0·319962
ar. co. log. sin. 1″	4·685575	ar. co. log. sin. 1″	4·685575
53″·413	1·727643	5″·966	0·775693

	°	′	″
Observed angle	51	9	29·744
		+	53·413
		−	5·966
Angle reduced to the horizon	51	10	17·191

It sometimes happens, when the steeple of a church or other remarkable object is selected as a signal, that the theodolite cannot be placed immediately over the point occupied by the axis of the signal. In this case the instrument must be removed to some convenient place near it, and a reduction is then applied to the observed angle in order to obtain the true angle at the centre.

3227.



It is required to determine the reduction to the centre.—Let A, Fig. 3227, be the situation of the axis of the signal observed from the stations B and C, O the place of the centre of the instrument. Put A, B, C, for the angles of the triangle A B C, and a, b, c, for the sides, respectively, opposite to them. Let $\mathrm{A\,O} = m$, angle $\mathrm{A\,O\,B} = \beta$, angle $\mathrm{A\,O\,C} = \gamma$, angle $\mathrm{B\,O\,C} = \mathrm{O}$; also, angle $\mathrm{A\,B\,O} = x$, $\mathrm{A\,C\,O} = y$. Now, angle $\mathrm{A} = \mathrm{B\,D\,C} - x = \mathrm{O} - x + y$; also, $\sin.\ x : \sin.\ \beta :: m : c$; $\sin.\ y : \sin.\ \gamma :: m : b$; $\therefore\ \sin.\ x = \dfrac{m \sin.\ \beta}{c}$, $\sin.\ y = \dfrac{m \sin.\ \gamma}{b}$. But since O is always near the station A, the angles x and y are very small, and therefore $\sin.\ x = x = x'' \sin.\ 1''$, $\sin.\ y = y = y'' \sin.\ 1''$, very nearly. Hence

$$\mathrm{A} = \mathrm{O} - \frac{m \sin.\ \beta}{c \sin.\ 1''} + \frac{m \sin.\ \gamma}{b \sin.\ 1''}. \qquad [5]$$

When all the angles have been observed and reduced to the plane of the horizon, if the triangle were a plane one, their sum ought to be equal to 180°, and thus the correctness of the observations might be verified. But in a spherical triangle the sum of the three angles exceeds 180° by a certain quantity, called the *spherical excess*; and as this can be easily calculated, we have the same means of verifying the operation in Spherical as in Plane Trigonometry.

It is required to determine the spherical excess in a small triangle measured on the surface of the earth.—Let A, B, C, be the three angles of a spherical triangle, r the radius of the sphere expressed in feet, x the area of the triangle in square feet, and ϵ the spherical excess given in seconds; we have then $x : \pi r^2 :: A + B + C - 180° (= \epsilon'') : 180 \times 60 \times 60$ seconds; $\therefore \epsilon = \frac{x \times 648000''}{\pi r^2}$;

and, if we suppose the mean value of r to be 20,888,761 ft., the logarithm of $\frac{\pi r^2}{648000}$ is equal to 9·32540. The value of x may be calculated as if the triangle were a plane one, without any sensible error. Hence we have the following

Rule.—From the logarithm of the area of the triangle, taken as a plane one in feet, subtract the constant logarithm 9·32540, the remainder will be the logarithm of the spherical excess in seconds, nearly.

When the triangles are very large, a more correct value of r will be obtained by computing for the mean latitude of the three stations, the radius of curvature of the meridian, and of the arc perpendicular to the meridian, and taking the mean of the two for the value of r.

The following example is taken from the Encyclopædia Britannica. The triangle connects the west of Scotland with Ireland, and is one of the largest which occurs in the Trigonometrical Survey.

The three stations are Benlomond, in Stirlingshire (A), Cairnsmuir-on-Deugh, in Kirkcudbright (B), and Knocklayd, in the county of Antrim (C); the arc c is 352037·62 ft., and the angles are as follows;—

	A	B	C
	° ′ ″	° ′ ″	° ′ ″
	56 43 29·97	79 42 28·69	43 34 38·36
	27·04		35·43
	28·72		
Mean ..	56 43 28·58		43 34 36·89

We shall first compute approximate values of the two sides, a, b (which will be afterwards required), from the formulæ $a = \frac{c \sin. A}{\sin. C}$, $b = \frac{c \sin. B}{\sin. C}$; and then compute the area from the formula, area $= \frac{1}{2} b c \sin. A$.

log. c = 5·54659	log. c = 5·54659	log. c = 5·54659
log. sin. A = 9·92223	log. sin. B = 9·99295	log. b = 5·70112
log. cosec. C = 0·16158	log. cosec. C = 0·16158	log. sin. A = 9·92223
		ar. co. log. 2 = 9·69897
log. a = 5·63040	log. b = 5·70112	log. area = 10·86891
a = 426970	b = 502480	

The latitude of Benlomond (the most northern station) is 56° 11′; and that of Knocklayd (the most southern) is 55° 10′; the mean of the two is 55° 40′. The values of the radii of curvature are therefore $r = 20924824$ ft., $r' = 20968900$ ft., mean = 20946862 ft.

$$\begin{aligned} \log. \frac{180 \times 60 \times 60}{\pi} &= 5·31443 \\ \log. r^2 &= 14·64224 \\ \hline & 9·32781 \\ \log. \text{area} &= 10·86891 \\ \hline \epsilon = 34''·76 \quad .. \quad .. & 1·54110 \end{aligned}$$

The sum of the three angles of the triangle being found from observation = 180° 0′ 34″·16, and the true spherical excess being 34″·76, it appears that the errors of observation in the three angles are = − 0″·60. If there were no reason to suppose that one angle has been determined more accurately than another, the error should be equally divided among the three angles; but as it generally happens that some of the angles have been determined from a greater number of observations, or from observations made under more favourable circumstances than the others, this error should be distributed among the three angles in such a manner that the respective corrections may be inversely proportional to the relative goodness of the observations. For this purpose we have the following rule, given by Gauss, but which our limits will not permit us to demonstrate in this work.

To apportion the error among the different angles.—*Rule.*—Let l, l', l'', &c., be the seconds of reading in any angle A, n the number of observations, and let m be the mean or average of the whole; then $m - l$, $m - l'$, $m - l''$, &c., are the errors of the individual observations, and the *weight* of the determination, or of the average m, will be given from this equation,

$$x = \frac{\frac{1}{2} n^2}{(m - l)^2 + (m - l')^2 + (m - l'')^2 + \&c.} \qquad [6]$$

In like manner, the weights y and z are found for the angles B and C. This error in the sum of the three angles is then divided into three parts, proportional to $\frac{1}{x}$, $\frac{1}{y}$, $\frac{1}{z}$, which are to be added respectively to the three angles A, B, and C.

To apply this to the last example, we have for the angle A, $l = 29''\cdot97$, $l' = 27''\cdot04$, $l'' = 28''\cdot72$; therefore $n = 3$, $m = \frac{1}{3}(l + l' + l'') = 28''\cdot58$. Hence

$$\frac{1}{x} = \frac{(1\cdot39)^2 + (1\cdot54)^2 + (0\cdot14)^2}{\frac{1}{2} \times 9} = \cdot961.$$

The angle B was given from one observation only. We may, therefore, assume the weight $y = \cdot1$, and $\frac{1}{y} = 10$.

At C the reciprocal of the weight $\frac{1}{z} = \frac{(1\cdot47)^2 + (1\cdot46)^2}{\frac{1}{2} \times 4} = 2\cdot146$.

Hence the error $-\,0''\cdot60$ is to be divided into three parts proportional to the numbers ·961, 10, 2·416; and consequently the corrections of the angles are, respectively, $+\,0''\cdot04$, $+\,0''\cdot46$, and $+\,0''\cdot10$. The true spherical angles, therefore, are

$$A = 56^\circ\ 53'\ 28''\cdot62;\ B = 79^\circ\ 42'\ 29''\cdot15;\ C = 43^\circ\ 44'\ 36''\cdot99.$$

The Calculation of the Sides of the Triangles.—The three spherical angles of the triangle being thus determined from observation, and corrected, and one of the sides being always known, either from actual measurement or calculation, it is necessary to show how the two other sides may be determined. The triangle may be considered as a spherical triangle, whose sides are very small, compared with the radius of the sphere; in which case three different methods have been employed for its solution;—1st. From the three given spherical angles, the angles formed by the chords are deduced, and from the given side of the triangle the corresponding chord is calculated. With these data the other chords are found by Plane Trigonometry, and from thence the arcs themselves. 2nd. A second method is by the theorem of Legendre, by which the spherical triangle is reduced to a plane triangle, whose sides are respectively equal in length to the sides of the triangle of the sphere. 3rd. The third method is to compute the sides by Spherical Trigonometry.

First Method.—To reduce the angle of a spherical triangle to the angle formed by the chords of the containing sides.—Let a, b, c, be the sides of the spherical triangle, and r the radius of the sphere, all measured in feet; also, let $\frac{a}{r} = \alpha$, $\frac{b}{r} = \beta$, $\frac{c}{r} = \gamma$, then will α, β, γ, be the sides of a similar triangle on a sphere whose radius is 1. Let A be the spherical angle opposite to the side a, and let $A - x$ be the corresponding angle formed by the chords. We have then

$$\begin{aligned}\cos. A &= \frac{\cos. \alpha - \cos. \beta \cos. \gamma}{\sin. \beta \sin. \gamma} \\ &= \frac{(1 - 2 \sin.^2 \frac{1}{2} \alpha) - (1 - 2 \sin.^2 \frac{1}{2} \beta)(1 - 2 \sin.^2 \frac{1}{2} \gamma)}{2 \sin. \frac{1}{2} \beta \cos. \frac{1}{2} \beta \times 2 \sin. \frac{1}{2} \gamma \cos. \gamma} \\ &= \frac{\sin.^2 \frac{1}{2} \beta + \sin.^2 \frac{1}{2} \gamma - \sin.^2 \frac{1}{2} \alpha}{2 \sin. \frac{1}{2} \beta \sin. \frac{1}{2} \gamma \times \cos. \frac{1}{2} \beta \cos. \frac{1}{2} \gamma} = \frac{\sin. \frac{1}{2} \beta \sin. \frac{1}{2} \gamma}{\cos. \frac{1}{2} \beta \cos. \frac{1}{2} \gamma}.\end{aligned}$$

Also, because chord $\alpha = 2 \sin. \frac{1}{2} \alpha$, chord $\beta =$ &c., we have, in the triangle formed by the chords,

$$\cos. (A - x) = \frac{\text{chord}^2 \beta + \text{chord}^2 \gamma - \text{chord}^2 \alpha}{2 \text{ chord } \beta \text{ chord } \gamma} = \frac{\sin.^2 \frac{1}{2} \beta + \sin.^2 \frac{1}{2} \gamma - \sin.^2 \frac{1}{2} \alpha}{2 \sin. \frac{1}{2} \beta \sin. \frac{1}{2} \gamma}.$$

Substituting this in the preceding equation, we get

$$\cos. A = \frac{\cos. (A - x)}{\cos. \frac{1}{2} \beta \cos. \frac{1}{2} \gamma} - \frac{\sin. \frac{1}{2} \beta \sin. \frac{1}{2} \gamma}{\cos. \frac{1}{2} \beta \cos. \frac{1}{2} \gamma};$$

$$\therefore \cos. (A - x) = \sin. \tfrac{1}{2} \beta \sin. \tfrac{1}{2} \gamma + \cos. \tfrac{1}{2} \beta \cos. \tfrac{1}{2} \gamma \cos. A. \qquad [7]$$

This expression is exact. But, because the three arcs, α, β, γ, are very small, $A - x$ is nearly equal to A, and therefore x is also very small. Hence

$$\cos. (A - x) = \cos. A \cos. x + \sin. x \sin. A = \cos. A + x \sin. A, \text{ nearly.}$$

Also, $\sin. \frac{1}{2} \beta = \frac{1}{2} \beta$, $\cos. \frac{1}{2} \beta = 1 - \frac{1}{8} \beta^2$, $\sin. \frac{1}{2} \gamma =$ &c., very nearly. Hence, substituting these values in equation [7], and reducing, we obtain

$$\begin{aligned}x \sin. A &= \tfrac{1}{4} \beta \gamma - \tfrac{1}{8} (\beta^2 + \gamma^2) \cos. A \\ &= \frac{(\beta + \gamma)^2 - (\beta - \gamma)^2}{16} - \frac{(\beta + \gamma)^2 + (\beta - \gamma)^2}{16} \cos. A;\end{aligned}$$

$$\begin{aligned}\therefore\ x &= \frac{(\beta + \gamma)^2}{16} \, \frac{1 - \cos. A}{\sin. A} - \frac{(\beta - \gamma)^2}{16} \, \frac{1 + \cos. A}{\sin. A} \\ &= \left(\frac{b + c}{4r}\right)^2 \tan. \tfrac{1}{2} A - \left(\frac{b - c}{4r}\right)^2 \cot. \tfrac{1}{2} A;\end{aligned}$$

or, if x be estimated in seconds,

$$x'' = \left(\frac{b+c}{4r}\right)^2 \frac{\tan.\ \tfrac{1}{2}\ A}{\sin.\ 1''} - \left(\frac{b-c}{4r}\right)^2 \frac{\cot.\ \tfrac{1}{2}\ A}{\sin.\ 1''}\,. \qquad [8]$$

Having obtained the three reduced angles, we find the chords of the spherical arcs intercepted between the stations, from Plane Trigonometry, and from them we deduce the arcs themselves, by means of the following formula;—

$$\frac{\alpha}{2} = \sin.\ \tfrac{1}{2}\,\alpha + \frac{1}{2}\,\frac{(\sin.\ \tfrac{1}{2}\,\alpha)^3}{3} + \frac{1.3}{2.4}\,\frac{(\sin.\ \tfrac{1}{2}\,\alpha)^5}{5} + \&c.\,;$$

and because chord $\alpha = 2 \sin.\ \tfrac{1}{2}\,\alpha$, and α is very small, if we neglect the terms after the second, and multiply by 2, we get $\alpha = \text{chord}\ \alpha + \dfrac{(\text{chord}\ \alpha)^3}{24}$; hence $\dfrac{a}{r} = \dfrac{\text{chord}\ a}{r} + \dfrac{(\text{chord}\ a)^3}{24\,r^3}$;

$$\therefore\quad a = \text{chord}\ a + \frac{(\text{chord}\ a)^3}{24\,r^2}\,. \qquad [9]$$

Example.—As an example of this method of solution, we will take the following;—

log. r^2	14·64224	(1)	9·46807
16 sin. 1″	5·88969	$(b-c)^2$	10·35468
	0·53193	cot. ½ A	0·26765
(1)	9·46807	1″·231	0·09040
$(b+c)^2$	11·86342		+ 11·583
tan. A	9·73235		− 1·231
11″·583	1·06384	$x =$	10·352

In the same manner, the corrections for the angles B and C will be found to be 14″·684 and 9″·724 respectively. Hence the three angles formed by the chords are

$$A' = 56^\circ\ 43'\ 18''{\cdot}27,\ B' = 79^\circ\ 42'\ 14''{\cdot}47,\ C = 43^\circ\ 34'\ 27''{\cdot}26,$$

and the sum of these = 180°, as it should be.

The chord c having been previously found equal to 352033·48 ft., we are enabled to find the lengths of the chords opposite A′ and B′ from the proportions

$$\sin.\ C' : \sin.\ A' :: \text{chord}\ c : \text{chord}\ a;\ \sin.\ C' : \sin.\ B' :: \text{chord}\ c : \text{chord}\ b.$$

cosec. C′	0·1615956	..	0·1615956
sin. A′	9·9222144	sin. B′	9·9929499
chord c	5·5465840	..	5·5465840
chord a	5·6303940	chord b	5·7011295

Hence chord $a = 426966{\cdot}69$ ft., chord $b = 352033{\cdot}48$ ft.

We have now to determine the lengths of the arcs a and b from the corresponding chords, from formula [9]. Making use of the logarithms already given in the preceding solution, we readily find

$$\frac{(\text{chord}\ a)^3}{24\,r^2} = 7{\cdot}39,\ \frac{(\text{chord}\ b)^3}{24\,r^2} = 12{\cdot}05,\ \frac{(\text{chord}\ c)^3}{24\,r^2} = 4{\cdot}14,$$

and therefore the lengths of the arcs are $a = 426974{\cdot}08$, $b = 502504{\cdot}51$, $c = 352037{\cdot}62$.

Second Method.—Legendre's Theorem.—If the three sides of a plane triangle be equal to the three sides of a small spherical triangle, respectively, the difference between each of the angles of the plane triangle, and the corresponding angle of the spherical triangle, will be equal to one-third of the spherical excess.—As before, let a, b, c, be the three sides of the small spherical triangle, measured in feet, r the radius of the sphere, and $\dfrac{a}{r} = \alpha$, $\dfrac{b}{r} = \beta$, $\dfrac{c}{r} = \gamma$. Also, let A be the spherical angle opposite to the side α, and A′ the corresponding angle in a plane triangle, whose sides are a, b, c. We have then, as before, $\cos.\ A = \dfrac{\cos.\ \alpha - \cos.\ \beta \cos.\ \gamma}{\sin.\ \beta \sin.\ \gamma}$.

If we now expand each of the quantities cos. α, cos. β, sin. β, &c., in a series, and arrange the terms according to the powers of α, β, γ, we shall find that the terms of the first order will be the same as if the triangle were rectilineal, and those of the second order will contain the fourth powers of the arc in the numerator, and the second powers in the denominator. Neglecting, therefore, all powers higher than the fourth, we have $\cos. \alpha = 1 - \frac{1}{2}\alpha^2 + \frac{1}{24}\alpha^4$, $\sin. \beta = \beta - \frac{1}{6}\beta^3$, $\cos. \beta =$ &c.

Substituting these values in the preceding equation, it becomes

$$\cos. A = \frac{\frac{1}{2}(\beta^2 + \gamma^2 - \alpha^2) + \frac{1}{24}(\alpha^4 - \beta^4 - \gamma^4) - \frac{1}{4}\beta^2\gamma^2}{\beta\gamma(1 - \frac{1}{6}\beta^2 - \frac{1}{6}\gamma^2)}.$$

And because $\frac{1}{1 - \frac{1}{6}(\beta^2 + \gamma^2)} = 1 + \frac{1}{6}(\beta^2 + \gamma^2) + \frac{1}{36}(\beta^2 + \gamma^2)^2 +$ &c., if we substitute this above, and neglect all terms containing powers higher than the fourth, we get

$$\cos. A = \frac{\beta^2 + \gamma^2 - \alpha^2}{2\beta\gamma} + \frac{\alpha^4 + \beta^4 + \gamma^4 - 2\alpha^2\beta^2 - 2\alpha^2\gamma^2 - 2\beta^2\gamma^2}{24\beta\gamma}$$

$$= \frac{b^2 + c^2 - a^2}{2bc} + \frac{a^4 + b^4 + c^4 - 2a^2c^2 - 2a^2c^2 - 2b^2c^2}{24bc \times r^2}.$$

But $\frac{b^2 + c^2 - a^2}{2bc} = \cos. A'$; also $2a^2b^2 + 2a^2c^2 + 2b^2c^2 - a^4 - b^4 - c^4 = (4 \text{ area})^2 = 16 S^2$;

$$\therefore \quad \cos. A = \cos. A' - \frac{2 S^2}{3bc \times r^2}. \qquad [10]$$

Let $A = A' + x$, then x is evidently a very small angle, consequently

$$\cos. A = \cos. A' \cos. x - \sin. x \sin. A' = \cos. A' - x \sin. A', \text{ nearly.}$$

Comparing this value of cos. A with equation [10], we have

$$x = \frac{2 S^2}{3 r^2 \times bc \sin. A'} = \frac{S}{3 r^2}.$$

Hence $$A' = A - \frac{S}{3r^2}. \qquad [11]$$

In like manner, $$B' = B - \frac{S}{3r^2}, \quad C' = C - \frac{S}{3r^2};$$

$$\therefore \quad A' + B' + C' = 180^\circ = A + B + C - \frac{S}{r^2}.$$

Hence $\frac{S}{r^2}$ is the excess of the three angles of the spherical triangle above two right angles, and each of the angles A, B, C, exceeds the corresponding angle of the plane triangle by one-third of this spherical excess.

Example.—Taking the same example as before, we find the spherical excess = 34″·76, and one-third of this excess = 11″·59. Hence A′ = 56° 43′ 17″·04, B′ = 79° 42′ 17″·56, C′ = 43° 34′ 25″·40. With these angles, and the given side c = 352037·62 ft., we then compute the other sides, a, b, by Plane Trigonometry, sin. C′ : sin. A′ :: c : a, and sin. C′ : sin. B′ :: c : b.

cosec. C	0·1615997	.. ..	0·1615997
sin. A′	9·9222127	sin. B′	9·9929511
c	5·5465891	.. ..	5·5465891
a	5·6304015	*b*	5·7011399

Hence a = 426974·06 ft., b = 502504·42 ft.

Third Method.—To compute the sides by Spherical Trigonometry.—By Trig.,

$$\sin. C : \sin. A :: \sin. c : \sin. a. \qquad [\alpha]$$

And since c and a are very small, compared with the radius of the sphere,

$$\frac{\sin. c}{r} = \frac{c}{r} - \frac{c^3}{6r^3}, \text{ nearly,} \qquad \therefore \sin. c = c\left(1 - \frac{c^2}{6r^2}\right)$$

$$\log. \sin. c = \log. c + \log. \left(1 - \frac{c^2}{6r^2}\right) = \log. c - \frac{M}{6r^2}c^2, \qquad [12]$$

nearly, these logarithms being taken from the common tables, and M being the modulus of the system. Having found log. sin. c from this expression, we get log. sin. a from proportion [α]. We then obtain a from the equation

$$\log. a = \log. \sin. a + \frac{M}{6r^2}a^2 = \log. \sin. a + \frac{M}{6r^2}\sin.^2 a. \qquad [13]$$

Example.—To apply this to the last example,

log. r^2	14·64224
$\frac{1}{6}$ M	8·85963
(1)	4·21739
c^2	11·09318
·0000204	$\bar{5}$·31057
sin. a	5·63037
	5·63037
(1)	4·21739
·0000301	$\bar{5}$·47813

log. c	5·5465891
	·0000204
sin. c	5·0465687
sin. A	9·9222287
cosec. C	0·1615740
sin. a	5·6303714
	·0000301
a	5·6304015

As the logarithm of a is exactly the same as that which we obtained by Legendre's method, the arc itself will also be the same as before.

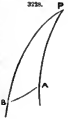
The logarithm of the side b is found in the same manner = 5·7011398, which only differs from the former logarithm by a unit in the last place of decimals.

In comparing these three methods together, Legendre's certainly appears to be the most simple, and the first method perhaps the most difficult. They are all, however, rendered considerably more easy in practice by means of auxiliary tables, previously calculated. The third method also has an advantage over the two others, in this respect, that if any of the angles (A for example) be one of the angles in another triangle, as in calculating the latitudes and azimuths, no further correction will be necessary; whereas, in the first and second methods, a new reduction must be made in order to obtain the angles for calculation. The whole may be brought under one view in the following Table;—

Stations.	Observed Angles.			Apportionment of Error.	Spherical Angles.	Chord Angles.	Mean Angles.	Opposite Chords.	Opposite Arcs.
	°	′	″	″	″	″	″		
A	56	43	28·58	+ 0·04	28·62	18·27	17·04	426966·69	426974·08
B	79	42	28·69	+ 0·46	29·15	14·47	17·56	502492·46	502504·51
C	43	34	36·89	+ 0·10	36·99	27·26	25·40	352033·48	352037·62
	180	0	34·16	0·60	34·76	0·00	0·00		

Calculation of the Latitudes, Longitudes, and Azimuths.—When all the sides of the principal triangles have been found, by one of the methods described in the preceding articles, we proceed to determine the latitudes and longitudes of the different stations, and the inclinations which the sides of the triangles make with the meridian. For this purpose it is necessary that the latitude of one of the stations and the azimuth of one of the sides should be found independently, by astronomical means; and from them we may determine the longitudes and latitudes of all the other stations, and the azimuths of the sides of the triangles. We shall first suppose the earth to be a sphere, and afterwards correct the error arising from this hypothesis.

3228.



Given the latitude of a station A, *the distance of* A *from another station* B, *and also the azimuth of* B *as seen from* A, *to determine the latitude of* B, *the earth being considered as a sphere.*—Let P, Fig. 3228, be the pole of the earth, P A, P B, the meridians of the stations A and B. Let the angle P A B = A, P B A = B, are P A = 90° − l, P B = 90° − l', and $l - l' = \lambda$; also, let the arc A B measured in feet = D, and in parts of the radius = δ; and let the radius of the earth measured in feet = r. We have then, from Spherical Trigonometry, cos. P B = cos. P A cos. A B + sin. P A sin. A B cos. A, or

$$\sin. l' = \sin. l \cos \delta + \cos. l \sin. \delta \cos. A. \qquad [\alpha]$$

But $\sin. l' = \sin. (l - \lambda) = \sin. l \cos. \lambda - \cos. l \sin. \lambda = \sin. l (1 - \frac{1}{2} \lambda^2) - \lambda \cos. l.$

Also, $\cos. \delta = - \frac{1}{2} \delta^2$, $\sin. \delta = \delta$, neglecting all the powers of δ and λ higher than the second.

Making these substitutions in equation [α], we have

$$\sin. l (1 - \tfrac{1}{2} \lambda^2) - \lambda \cos. l = \sin. l (1 - \tfrac{1}{2} \delta^2) - \delta \cos. l \cos. A;$$

$$\therefore \lambda = \delta \cos. A + \tfrac{1}{2} (\delta^2 - \lambda^2) \tan l.$$

For a first approximation, we may neglect the second powers of δ and λ, and assume $\lambda = \delta \cos. A$, which is the same thing as if we supposed the meridians at A and B to be parallel. Substituting this first value of λ in the second member of the last equation, we obtain

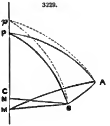
$$\lambda = \delta \cos. A + \tfrac{1}{2} \delta^2 \sin.^2 A \tan. l.$$

Here λ and δ are measured in parts of the radius. If λ'' be the number of seconds in λ, then $\lambda = \lambda'' \sin. 1''$; also $\delta = \frac{D}{r}$. Making these substitutions, the last equation becomes

$$\lambda'' = \frac{D \cos. A}{r \sin. 1''} + \frac{D^2 \sin.^2 A \tan. l}{2 r^2 \sin. 1''}. \qquad [14]$$

To determine the same when the spheroidal figure of the earth is taken into consideration.—Let P A, P B, Fig. 3229, be the meridians of A and B, the earth being considered as a spheroid; let A M, B N, be the normals to the surface meeting the polar axis in M and N; join B M. Suppose A p B to be the surface of a sphere whose centre is M, and radius M A. Then, because the arc A B is very small, and A M is a normal to the spheroid, it is nearly equal to the radius of curvature at A, therefore the surface of the sphere will very nearly pass through B, and the difference between the arc A B on the sphere and on the spheroid will be altogether insensible. The spherical triangle p A B may be considered as that whose solution we have just given, and on this supposition B M $p = 90° - l'$ is the colatitude of B. But the true colatitude of B is the angle B N P $= 90° - L$, which is greater than B M P by the angle M B N. Let $l - l' = \lambda$, $l' - L = M B N = \phi$; we have then, in the triangle B M N,

3229.



$$\sin. \phi = \frac{M N}{B M} \sin. B N M = \frac{C M - C N}{B M} \cos. L;$$

but $C M = A M . e^2 \sin. l$, $C N = B N . e^2 \sin. L$, therefore

$$\sin. \phi = e^2 \cos. L \left(\frac{A M}{B M} \sin. l - \frac{B N}{B M} \sin. L\right).$$

And since $\frac{A M}{B M}$ and $\frac{B N}{B M}$ differ from unity by a quantity of a very minute order, we have

$$\sin. \phi = e^2 \cos. L (\sin. l - \sin. L), \text{ very nearly.}$$

Now, $\sin. L = \sin. \{ l - (\lambda + \phi) \} = \sin. l - (\lambda + \phi) \cos. l$, nearly. Also, $\sin. \phi = \phi$, very nearly; therefore $\phi = e^2 (\lambda + \phi) \cos. L \cos. l$. Hence, transposing and dividing,

$$\phi = \frac{e^2 \lambda \cos. L \cos. l}{1 - e^2 \cos. L \cos. l} = e^2 \lambda \cos. L \cos. l, \text{ nearly;}$$

$$\therefore \quad \phi = e^2 \lambda \cos.^2 l, \text{ nearly, and } \lambda + \phi = \lambda (1 + e^2 \cos.^2 l).$$

Hence, on the spheroid, the difference of latitude

$$l - L = \left\{\frac{D \cos. A}{r \sin. 1''} + \frac{D^2 \sin.^2 A \tan. l}{2 r^2 \sin. 1''}\right\} (1 + e^2 \cos.^2 l), \qquad [15]$$

where $r = A M$, the normal to the surface at the station A.

The same things being given, to find the difference of longitude.—The difference of longitude on the sphere is the angle A p B, which is equal to A P B, the difference of longitude on the spheroid. We have then, by Spherical Trigonometry, $\sin. B p : \sin. A :: \sin. \delta : \sin. p :: \delta : p$. But $\sin. B p = \cos. l' = \cos. L$, very nearly, $\delta = D + r$, $p = P = P'' \sin. 1''$, therefore

$$P'' = \frac{D \sin. A}{r \cos. L \sin. 1''}. \qquad [16]$$

To find the azimuth of A *as seen from* B.—In the spherical triangle A p B we have, from Napier's analogies, $\cos. \frac{1}{2} (p B + p A) : \cos. \frac{1}{2} (B p - p A) :: \cot. \frac{1}{2} p : \tan. \frac{1}{2} (A + B)$.

Now, $\frac{1}{2} (p B + p A) = \frac{1}{2} (90° - l') + \frac{1}{2} (90° - l) = 90° - \frac{1}{2} (l + l')$, $\frac{1}{2} (p B - p A) = \frac{1}{2} (l - l')$, $\frac{1}{2} (A + B) = 90° - \frac{1}{2} (180 - A - B)$.

Making these substitutions, this proportion becomes

$$\begin{aligned} \sin. \tfrac{1}{2} (l + l') : \cos. \tfrac{1}{2} (l - l') &:: \cot. \tfrac{1}{2} p : \cot. \tfrac{1}{2} (180° - A - B) \\ &:: \tan. \tfrac{1}{2} (180° - A - B) : \tan \tfrac{1}{2} p. \end{aligned}$$

And because the distance A B is always very small, compared with the radius of the earth, A + B is nearly equal to 180°, and therefore 180° − A − B is a very small angle. Also, $\frac{1}{2} p$ or $\frac{1}{2}$ P is very small. We may therefore substitute the arcs for the tangents, and also L for l', without sensible error. Hence, forming an equation, we obtain

$$B = 180° - A - P \frac{\sin. \frac{1}{2} (l + L)}{\cos. \frac{1}{2} (l - L)}. \qquad [17]$$

The angle B, which we have calculated, is the spherical angle p B A, or the angle contained between the planes M B p, M B A; but the true azimuth is the spheroidal angle contained between the planes N B P, N B A; the difference, however, between these angles has been proved by Delambre to be so small as not to be sensible in practice.

In the trigonometrical survey the angles are measured either from the north or south to the east or west; but in the "base du système mètrique," the angles are measured from the south towards the west, entirely round the circle.

To determine the azimuth of one of the signals independently from astronomical observations.—The general principle of the method is this. The error of a clock or chronometer is found either by means of a transit instrument, or by observations of equal altitudes, or by single altitudes, if the latitude of the place be well known. The observer then takes the angle (θ) between the signal and the sun, or a star, when near the horizon, and notes the time when the observation was made. The azimuth of the heavenly body is also calculated for this time; the latitude and declination being known. Then the sum or difference of the angle θ and the azimuth of the heavenly body will give the azimuth of the signal required. The refraction will scarcely affect the result, but a small error in the time would produce a considerable error in the azimuth.

The method adopted in the trigonometrical survey was to take the mean of the two angles observed with the theodolite, between a flagstaff and the pole star at its greatest elongation east and west. But, from the great altitude of the pole star in our latitudes, any error in the adjustment of the cross axis of the theodolite to horizontality, would materially affect the resulting azimuth.

Example.—From the Trigonometrical Survey, vol. ii., p. 88, the distance of Black Down from Dunnose = 314397·5 ft., the latitude of Dunnose = 50° 37′ 7″·3 N., and azimuth of Black Down, as seen from Dunnose = 84° 54′ 52″·5 N.W. Required the latitude and longitude of Black Down, and the azimuth of Dunnose, as seen from Black Down.

To find the latitude.—The normal A M, which is equal to r the radius of the curvature at A, perpendicular to the meridian, is found = 20963000, nearly.

log. r	7·32145
sin. 1″	4·68557
	2·00702
ar. co.	7·99298
D	5·49735
cos. A	8·94763
$(1 + e^2 \cos.^2 l)$	0·00116
274″·87	2·43912

$2 r^2$ sin. 1″	9·62950
ar. co.	0·37050
D²	10·99470
sin.² A	9·99658
tan. l	0·08573
$(1 + e^2 \cos.^2 l)$	0·00116
28″·10	1·44867

Hence $l - \text{L} = \times\, 274''\cdot 87 + 28''\cdot 10 = -4'\, 6''\cdot 77$, and $\text{L} = l + 4'\, 6''\cdot 77 = 50°\, 41'\, 14''\cdot 07$.

To find the Difference of Longitude.

ar. co. log. r sin. 1″ ..	7·99298
D	5·49735
sin. A	9·99829
sec. L	0·19822
4862″·3	3·68684

Hence P = 1° 21′ 2″·3; and since the longitude of Dunnose was previously found = 1° 11′ 36″, therefore, the long. of Black Down = 2° 32′ 38″·3.

To find the Azimuth.

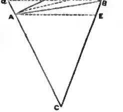
sin. ½ (l + L)	9·88836
cos. ½ (L − l)	0·00000
P	3·68684
3760″·12	3·57520

Hence
P B A = 180° − A − 1° 2′ 40″·12 = 94° 2′ 27″·38.
The observed angle P B A was 94° 2′ 22″·75.

In the survey, the value of P is found to be 1° 20′ 46″·4. The difference, 15″·9, arises from an erroneous assumption in the length of the perpendicular degree, which gives all the longitudes on the southern coast of England too small.

Heights of the Stations, and Terrestrial Refraction.—To find the altitude of the station B *above the station* A.—Let C, Fig. 3230, be the centre of the earth, supposed to be a sphere, and A and B two stations on its surface. Draw A D, B D, perpendicular to the radii C A, C B, respectively, in the plane C A B; and suppose a and b to be the apparent places of A and B as seen from each other, and elevated by refraction. If the rays of light proceeded in straight lines, the angle D A B would be the depression of B below the horizon of A, and D B A the depression of A below the horizon of B. And because D A C, D B C, are right angles, C + D = 180° = D A B + D B A + D, and ∴ C = D A B + D B A. Also, since the distance A B is known, and the radius of the earth (sufficiently near for this purpose), the angle C can easily be found.

3230.



Let α, β, be the observed depressions at A and B respectively, and ρ, ρ', the two refractions, then

$$\text{D A B} = \alpha + \rho,\ \text{D B A} = \beta + \rho',\ \text{and}\ (\alpha + \rho) + (\beta + \rho') = \text{C};$$

$$\therefore\ \text{mean refraction}\ \tfrac{1}{2}(\rho + \rho') = \tfrac{1}{2}(\text{C} - \alpha - \beta). \qquad [18]$$

Let E be the point in C B which is on the same level with A, then C E = C A, and E B is the altitude of B above A, which is to be determined. Join A E, then the angle D A E $=90^\circ-$ C A E $=\frac{1}{2}$ C, therefore the angle

$$\mathrm{B\,A\,E} = \phi = \mathrm{D\,A\,E} - \mathrm{D\,A\,B} = \tfrac{1}{2}\mathrm{C} - (\alpha + \rho); \qquad [19]$$

and since the angle B A E is always very small, and B E A very nearly a right angle,

$$\mathrm{B\,E} = \mathrm{A\,E} \times \phi = \mathrm{D} \times \phi'' \sin. 1''. \qquad [20]$$

If one of the stations, B for example, is elevated above the horizon of A, β must be considered negative. Also, each observation must be reduced, previously to the calculation, to the place of the axis of the instrument.

Example.—At Allington Knoll the top of the staff on Tenterden steeple was depressed 3′ 5″; and the axis of the instrument was 5½ ft. above the ground: on Tenterden steeple the ground at Allington Knoll was depressed 3′ 35″, and the axis of the instrument was 3·1 ft. below the top of the staff. The distance between the stations being 61,777 ft., it is required to calculate the mean refraction, and also the height of Tenterden steeple above Allington Knoll. (Trig. Survey, vol. i., p. 176.)

The angle which a perpendicular height of 5·5 ft. subtends at the distance = 61777 ft. is $\frac{5\cdot5}{61777} \div \overline{\sin. 1''} = 18''\cdot4$; and in like manner the angle which 3·1 ft. subtends is 10″·4. Hence

	′	″
Depression of the top of the staff	3	51
Correction due to 3·1 ft.	+	10·4
Depression of instrument	1	1·4
Depression of the ground	3	35
Correction due to 5½ ft.	−	18·4
Depression of instrument	3	16·6

Length of perpendicular degree at Tenterden (vol. i., p. 168) = 61185 fathoms.

Fathoms.		Feet.		°		′	″
61185	:	61777	::	1	:	10	6

	′	″
β	4	1·4
α	3	16·6
$\alpha + \beta$	7	18·0
C	10	6
$\rho \times \rho'$	2	48
Mean refraction	1	24

Hence $\phi'' = \frac{1}{2}\mathrm{C} - (\alpha + \text{mean refr.}) = 22''\cdot4$, and $h = \mathrm{D} \times \phi'' \sin. 1'' = 6\cdot7$ ft.

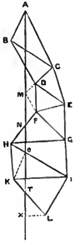
The vertical height of the axis at Allington Knoll had been previously found to be 329 ft., so that the height of the axis on Tenterden steeple was 322·3 ft.

To find the absolute altitudes it is necessary that the heights of one or more of the stations be ascertained by actually levelling down to the surface of the sea. The heights of all the intermediate stations are then determined by the reciprocal angles of elevation or depression, carried on from station to station, and it is obvious that a verification will be obtained for every three stations; for the difference of altitude between A and B, when found from direct observation, ought to be the same as when deduced from the difference of the heights of each of those stations and a third station C.

In the preceding example the effect of refraction is $\frac{1}{7}$ of the intercepted arc. In other cases the refraction varied from $\frac{1}{5}$ to $\frac{1}{20}$ of the contained arc. When reciprocal observations could not be obtained, $\frac{1}{12}$ of C was generally assumed as a mean value of ρ, in order to obtain the angle ϕ in equation [19].

Measurement of the Arcs of the Meridian, and the Arcs parallel to the Equator.—When a chain of triangles has been formed nearly in the direction of the arc of a meridian, and all the sides have been computed, according to the preceding rules, we are enabled to determine the length of the arc of the meridian intercepted between the parallels of the extreme stations. For this purpose two different methods have been adopted, which we shall briefly explain.

3231.



The Method of Oblique-angled Triangles.—To measure the arc of the meridian intercepted between the parallels of A *and* L. — Let A B C D . . ., Fig. 3231, be a chain of triangles lying nearly in the direction of the meridian A X. All the sides of the triangles are supposed to have been previously computed, and the angle C A X is given from observation. Produce C D to M, join F M; and, from the last station L, draw L X perpendicular to the meridian A X. The following spherical triangles will then be most easily solved, according to Legendre's method, by first computing the spherical excess in each case, and then deducting one-third of this excess from each of the spherical angles.

In the triangle A C M, there are given A C, ∠ A C M, ∠ C A M, to find A M, C M, and ∠ A M C.

Then D M = C M − C D, and ∠ M D F = 180° − C D F.

In the triangle D M F are given D F, D M, ∠ D, to find M F, ∠ D M F, ∠ D F M.

$$\angle \mathrm{F\,M\,N} = 180^\circ - (\mathrm{A\,M\,C} + \mathrm{D\,M\,F}); \quad \angle \mathrm{M\,F\,N} = \mathrm{D\,F\,N} - \mathrm{D\,F\,M}.$$

In the triangle M F N are given M F, ∠ F M N, ∠ M F N, to find M N, F N, and ∠ M N F.

H N = F H − F N, and ∠ F N M = H N O.

In the triangle H N O are given H N, ∠ H N O, ∠ N H O, to find N O, H O, and ∠ H O N.

Lastly, in resolving the triangles H O K, O K T, L X T, we find O T and T X. Hence we have, by addition, A X = A M + M N + N O + O T + T X.

It must be observed, however, that the point X is not in the same parallel of latitude with L. Suppose the latitude of A to be greater than that of X, and let L = the latitude of L, and L + x = the latitude of X, also put L X = p; if then we suppose X A produced to meet the meridian of L in the pole P, we shall have cos. P L = cos. P X cos. L X, or

$$\sin.(L + x) = \sin. x \cos. L + \sin. L \cos. x = \frac{\sin. L}{\cos. p}.$$

But sin. $x = x - \frac{1}{6} x^3 +$ &c., cos. $x = 1 - \frac{1}{2} x^2 +$ &c., cos. $p = 1 - \frac{1}{2} p^2 +$ &c., consequently we have cos. L (x − &c.) + sin. L $(1 - \frac{1}{2} x^2 +$ &c.) = sin. L $(1 + \frac{1}{2} p^2 +$ &c.);

$$\therefore \quad x = \tan. L \left(\tfrac{1}{2} p^2 + \tfrac{1}{2} x^2\right) + \text{\&c.}$$

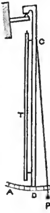
Hence x is of the second order, with respect to p, and therefore the term involving x^2 being of the fourth order may be neglected. Hence $x = \frac{1}{2} p^2$ tan. L. In this expression p and x are measured in parts of the radius; if we suppose them to be measured in feet, we must substitute $\frac{p}{r}$ and $\frac{x}{r}$ for p and x, therefore the correction to be added to A X (the latitude of A being greater than that of X) is

$$x = \frac{p^2}{r^2} \tan. L. \qquad [21]$$

The Method of Parallels.—The method employed by Delambre to determine the length of the arc of the meridian, was to project on the principal meridian all the stations to the east, by means of circles parallel to the equator. He then computed the distance between every two succeeding parallels from formula [15]; the sum of all these distances will give the entire length of the meridian between the extreme stations. Having done the same for the stations to the west of the meridian, these two sums ought to give the same value for the length of the total arc of the meridian, and thus the two computations serve to verify each other. If the two sums do not agree, a mean should be taken between the two for the total arc. This method, however, can only be applied when the dimensions of the earth are previously known with tolerable accuracy.

When the distance between the parallels of the extreme stations has been determined in this manner, it only remains to determine the latitudes of these stations, and the amplitude of the corresponding celestial arc. This is the most difficult part of the whole operation. The error of a single second in the difference of latitude is equivalent to about 100 ft. on the terrestrial meridian, and therefore it is obvious that an error in the latitude is of far more importance than any which can affect the measurement of the base, the angles of the triangles, or the direction of the meridian. In the English survey, and in India, the latitudes were observed with a zenith sector.

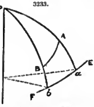
3232.



The principle of the zenith sector is this:—A B, Fig. 3232, is an arc of a circle, having a long radius C D, to which is firmly fixed a telescope T of the same length. The instrument is suspended vertically, and the telescope (with the arc fixed to it) can be moved in the plane of the meridian a few degrees on each side of the vertical line so as to observe stars within a few degrees of the zenith. A plumb line C P suspended from the centre of the instrument and passing over the arc A B, shows the angle between C D and the vertical line C P. This instrument can be turned half round in azimuth, so that if observations be made on the same stars in the two positions any error in the place of the zero of graduation will be entirely removed; for the zenith distance will be as much too great in the one case as it was too little in the other. The telescope of the sector used in the British survey was 8 ft. in length.

In France the small repeating circle, before described, was used to determine the latitudes; and it has justly been doubted whether this instrument can be safely relied on for determining so important an element as the latitude.

3233.



To determine the length of an arc parallel to the equator.—Let A B, Fig. 3233, be one of the sides of a chain of triangles which lie in a direction nearly perpendicular to the meridian, and let E F be the parallel on which the sides of all the triangles are to be projected. Draw the meridians P A a, P B b, then it is required to determine the length of the arc $a b$ in feet. Let L = the latitude of the parallel E F, l = the latitude of B, z = the azimuth P A B, N = the normal at b, and N' = ditto at B: also, let A B measured in feet = D, and in parts of the radius = δ. We have then in the spherical triangle A P B, sin. P : sin. z :: sin. δ : cos. l, and because P and δ are small arcs, sin. $P = P - \frac{1}{6} P^3$, sin. $\delta = \delta - \frac{1}{6} \delta^3$, very nearly: therefore, making an equation and transposing, $P = (\delta - \frac{1}{6} \delta^3) \frac{\sin. z}{\cos. l} + \frac{1}{6} P^3$. As a first approximation, we have $P = \delta \frac{\sin. z}{\cos. l}$; substituting this value of P in the second member of the last equation, we get

$$P = \delta \frac{\sin. z}{\cos. l} - \frac{1}{6} \delta^3 \frac{\sin. z}{\cos. l} \left(1 - \frac{\sin.^2 z}{\cos.^2 l}\right). \qquad [a]$$

Let H be the centre of the circle E F, and let $a b$ measured in feet $= p$, then $p : b\,H :: $ measure of the angle $a\,H\,b$ or $P : 1$; $\therefore p = P \times b\,H = P \times N \cos. L$, equation [26]; also $\delta = \frac{D}{N'}$. Making these substitutions in equation [a], we get

$$p = \frac{N \cos. L}{N' \cos. l} \left\{ D \sin. z - \frac{D^3 \sin. z}{6 N'^3} \left(1 - \frac{\sin.^2 z}{\cos.^2 l}\right) \right\}. \qquad [22]$$

By applying this formula to all the sides of the triangles, the sum of these projections will give the required length of the total arc.

We have now to determine the astronomical difference of longitude from observation. In the Philosophical Transactions for 1824, an account is given of some experiments performed by Dr. Tiarks, for determining the differences of longitude of Dover and Falmouth. Twenty-four chronometers were transported by sea three several times from the one place to the other, by which means the difference of longitude was determined to be 6° 22′ 6″; and as the length of the parallel found from the survey was 1,474,672 ft., we have the length of a degree of parallel in latitude 50° 44′ 24″, equal to 231,563 ft. The difference of longitude of Marennes and Padua was determined by five signals, at five intermediate stations. The length of the parallel in feet was found, from triangulation, to be 1,010,996 mètres, or 3,316,976 English ft., and the difference of longitude was 12° 59′ 3″·75. This gives for the mean length of a degree in latitude 45° 43′ 12″, found from the whole arc between Marennes and Padua, 255,470 ft.; the length of the degree found from the partial arc between Marennes and Geneva was 255,546 ft. Both these results are greater than a degree in the same parallel of latitude on a regular spheroid, which most nearly represents the meridional arcs; but no great reliance can be placed on these numbers, as the determination of the longitudes was attended with considerable difficulty.

The Figure of the Earth.—If the earth were perfectly fluid, and had no motion of rotation about an axis, it would assume a spherical form; for in this case there would be no tendency in the fluid to run in any direction, and therefore it would be in a state of equilibrium. But if any portion of the surface were farther removed from the centre than the rest, the pressure arising from the protuberant would be greater than that from the less elevated parts, and therefore the equilibrium would be destroyed.

But since the earth revolves on its axis, every particle has a tendency to recede from that axis proportional to its distance; consequently its gravity will be diminished, and the columns of fluid at the equator being composed of parts that are lighter, must be extended in length in order to balance the columns in the direction of the axis. It has been proved by Maclaurin and succeeding writers, that a mass of homogeneous fluid will be in equilibrium if it be formed into an oblate spheroid, such that the polar diameter shall be to the equatorial diameter as the attraction at the equator, diminished by the centrifugal force there, is to the attraction at the pole. And as it appears from experiments on the vibration of pendulums that the centrifugal force is to the force of gravity at the equator as 1 to 289, it may be demonstrated that a homogeneous fluid of the same mean density as the earth would be in equilibrium if the ratio $\frac{a - b}{a} = \frac{5}{4} \frac{1}{289} = \frac{1}{231}$, nearly, a being the equatorial, and b the polar diameter; that is, if $b : a :: 230 : 231$.

If the fluid mass of the earth be supposed not to be homogeneous, but to be formed of strata that increase in density towards its centre, the solid of equilibrium will still be an elliptic spheroid, but less oblate than before. Now, as it appears, from experiments made on the density of the mountain Schehallien, in Scotland, and also from those of Cavendish, that the mean density of the earth is greater than the density at the surface, it follows, that if the earth be a solid of equilibrium, the ratio $\frac{a - b}{b}$ will be less than before, or less than $\frac{1}{230}$.

If the earth were homogeneous, the increase of gravity from the equator to the pole would be $\frac{1}{230}$ G, G being the gravity at the equator; and the gravity g, at any latitude l, would be represented by the equation $g = G\,(1 + \frac{1}{230} \sin.^2 l)$. But if the density of the earth increase towards the centre, the ratio $\frac{a - b}{b}$, and the increase of gravity from the equator to the pole, divided by the gravity at the equator (γ), will no longer be expressed by the same fraction, but the sum of the two fractions is constant, and equal to twice the value of $\frac{a - b}{b}$, which the spheroid would have if it were homogeneous, that is,

$$\frac{a - b}{b} + \gamma = \frac{5}{2} \frac{1}{289} \cdot 00865, \text{ and } g = G\,(1 + \gamma \sin.^2 l). \qquad [23]$$

This theorem was first given by Clairant, and is of great importance in determining the figure of the earth from experiments with the pendulum.

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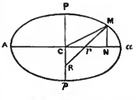

With respect to the values given to q, see our article on GUNNERY. We shall now proceed to show how the figure of the earth is to be determined from geodetic operations. We shall, therefore, first consider the different properties of an oblate spheroid, and then compare them with the results deduced from observation.

Let A P a p, Fig. 3234, be an ellipse, which, by its revolution about its minor axis P p, generates an oblate spheroid. Let A C = a, C P = b, the eccentricity = $a\,e$, the ordinate M N = y, C N = x, the normal M r = n, M R = N, the radius of curvature at M = ρ, and the latitude of M, or the angle M r a = l. Now, the equation to the ellipse is $a^2 y^2 + b^2 x^2 = a^2 b^2$.

Also $y = n \sin. l$, and $x = \frac{a^2}{b^2} \times \mathrm{N}\,r = \frac{a^2}{b^2} n \cos. l$; $\therefore\ a^2 n^2 \sin.^2 l + \frac{a^2}{b^2} n^2 \cos.^2 l = a^2 b^2$; consequently $n = \frac{b^2}{\surd (a^2 \cos.^2 l + b^2 \sin.^2 l)}$. And because $b^2 = a^2 (1 - e^2)$, therefore

$$a^2 \cos.^2 l + b^2 \sin.^2 l = a^2 (1 - e^2 \sin.^2 l);$$

hence

$$n = \frac{a(1 - e^2)}{\surd(1 - e^2 \sin.^2 l)}, \qquad [24]$$

$$x = \frac{a \cos. l}{\surd(1 - e^2 \sin.^2 l)}, \qquad y = \frac{a(1 - e^2) \sin. l}{\surd(1 - e^2 \sin.^2 l)}, \qquad [25]$$

$$\mathrm{N} = \frac{x}{\cos. l} = \frac{a}{\surd(1 - e^2 \sin.^2 l)}, \qquad [26]$$

$$\mathrm{C}\,r = \frac{a e^2 \cos. l}{\surd(1 - e^2 \sin.^2 l)} = \mathrm{N} e^2 \cos. l, \qquad [27]$$

$$\mathrm{C\,R} = \frac{a e^2 \sin. l}{\surd(1 - e^2 \sin.^2 l)} = \mathrm{N} e^2 \sin. l, \qquad [28]$$

$$\mathrm{C\,M} = \sqrt{x^2 + y^2} = a \sqrt{\left(\frac{1 - (2e^2 - e^4) \sin.^2 l}{1 - e^2 \sin.^2 l}\right)}, \qquad [29]$$

$$\rho = \frac{a^2}{b^4} n^3 = \frac{a(1 - e^2)}{(1 - e^2 \sin.^2 l)^{\frac{3}{2}}}. \qquad [30]$$

The lengths of two degrees on the meridian in given latitudes being known from measurement, it is required to determine the polar and equatorial diameters.—Let D, D′, be the lengths of two degrees in feet; l, l', the latitudes of their middle points; ρ, ρ', the radii of curvature at those points; then, since the two arcs are very small compared with their radii, we may suppose them to be arcs of two circles whose radii are ρ, ρ', without sensible error. Hence $180^\circ : 1^\circ :: \pi \rho : \mathrm{D}$;

$$\therefore\ \rho = \frac{180}{\pi} \mathrm{D} = \mu \mathrm{D};\ \text{and}\ \rho' = \mu \mathrm{D}',$$

μ being substituted for $\frac{180}{\pi}$. Hence, therefore, expanding the value of ρ, and neglecting higher powers of e than the second, we have, from equation [30],

$$\mathrm{D} = \frac{\rho}{\mu} = \frac{a(1 - e^2)}{\mu} (1 + \tfrac{3}{2} e^2 \sin.^2 l): \qquad [31]$$

$$\mathrm{D}' = \frac{\rho'}{\mu} = \frac{a(1 - e^2)}{\mu} (1 + \tfrac{3}{2} e^2 \sin.^2 l):$$

$$\therefore\ \frac{\mathrm{D}}{\mathrm{D}'} = \frac{1 + \frac{3}{2} e^2 \sin.^2 l}{1 + \frac{3}{2} e^2 \sin.^2 l'} = 1 + \tfrac{3}{2} e^2 \sin.^2 l - \tfrac{3}{2} e^2 \sin.^2 l';$$

$$\therefore\ e^2 = \frac{2}{3} \frac{\mathrm{D} - \mathrm{D}'}{\mathrm{D}'(\sin.^2 l - \sin.^2 l')} = \frac{2}{3} \frac{\mathrm{D} - \mathrm{D}'}{\mathrm{D}' \sin. (l + l') \sin. (l - l')}. \qquad [32]$$

If $l' = 0$, or the degree is at the equator, the length of the degree $\mathrm{D}' = \frac{a(1 - e^2)}{\mu}$. Hence it follows, that the excess of the degrees of the meridian above a degree of the meridian at the equator, is as the square of the sine of latitude.

The length of a degree parallel to the equator, and the length of a degree of the meridian, being known from measurement, to determine the polar and equatorial diameters.—Let Δ be the length of a degree parallel to the equator, at a place whose latitude $= \phi$. Then the radius of this circle $x = \frac{a \cos. l}{\sqrt{(1 - e^2 \sin.^2 l)}}$, equation [25]; therefore $\Delta = \frac{x}{\mu} = \frac{a \cos. l}{\mu \sqrt{(1 - e^2 \sin.^2 l)}}$. Expanding this expression, and neglecting the powers of e higher than the second,

$$\Delta = \frac{a \cos. l}{\mu} (1 + \tfrac{1}{2} e^2 \sin.^2 l). \qquad [33]$$

From this equation, and equation [31], we can determine the values of e^2 and a, when D and Δ are known.

We shall now give some examples of the geodetic measurements which have been executed in our own country and in India. They are part of those which M. Schmidt has selected as the best for the purpose of determining the magnitude and figure of the earth. With these deta he has found $a = 20921665$ ft., $b = 20852394$ ft. Ellipticity $= \frac{a - b}{a} = \frac{1}{302 \cdot 03}$. Degree at the equator $= 362732$; degree in latitude $45° = 364543 \cdot 5$.

No.	Country.	Latitude of Middle Points.	Arc measured.	Length in Feet.	Length of a Degree.	Difference.
		° ′ ″	° ′ ″			
1	India	12 32 21	1 34 56·4	574,368	362,988	+ 83
2	"	9 34 43	2 50 10·5	1,029,171	362,863	+ 29
3	"	13 2 54	4 6 11·3	1,489,198	362,873	− 46
4	"	16 34 42	2 57 21·7	1,073,409	363,125	+ 96
5	"	19 34 34	3 2 35·9	1,105,499	363,257	+118
6	"	22 36 32	3 1 19·9	1,097,320	363,084	−184
7	England ..	51 25 18	1 36 20·0	586,319	364,952	+256
8	"	52 50 30	1 14 3·4	450,018	365,036	−411
9	"	54 0 56	1 6 49·7	406,516	365,109	−107

The last column in this Table is the difference between the length of a degree computed with the values of a and b, given above, and the length of a degree given by measurement. These differences must be supposed to arise either from errors in the observations, or from local irregularity of form or density. The most probable source of error is in determining the latitudes; for an error of a single second in the difference of latitude is equivalent to 100 ft. measured on the ground. On this account, the largest arcs may be considered the best; for the probable error is the same, whether the arcs be great or small.

To these examples we may add the results of four arcs of parallel, measured in different countries, and also their errors, compared with the degrees computed from formula [33].

No.	Country.	Latitude.	Measured Degree.	Difference.
		° ′ ″		
1	Mouth of the Rhone	43 31 50	266,315	+1191
2	Beachy Head to Dunnose	50 44 24	232,331	+ 789
3	Dover to Falmouth	50 44 24	231,579	+ 37
4	Padua to Marennes	45 43 12	255,480	+ 110

To determine the length of any arc of the meridian.—Let the arc a M, Fig. 3234, measured from the equator $= s$, then $ds = \sqrt{dx^2 + dy^2}$, and if we differentiate the values of x and y, given in formula [25], we shall readily find $ds = \frac{a(1 - e^2)\,dl}{(1 - e^2 \sin.^2 l)^{\frac{3}{2}}} = \rho\,dl$. Expanding this expression, and neglecting all powers of e higher than the fourth, we get

$$ds = a\,dl\,(1 - e^2)(+ \tfrac{3}{2} e^2 \sin.^2 l + \tfrac{15}{8} e^4 \sin.^4 l);$$

and since $\sin.^2 l = \frac{1}{2}(1 - \cos. 2l)$, $\sin.^4 l = \frac{1}{8}(3 - 4 \cos. 2l + \cos. 4l)$, this equation becomes $ds = a\,dl\,(1 - e^2)(\text{A} - \text{B} \cos. 2l + \text{C} \cos. 4l)$, where

$$\text{A} = 1 + \tfrac{3}{4} e^2 + \tfrac{45}{64} e^4, \quad \text{B} = \tfrac{3}{4} e^2 + \tfrac{15}{16} e^4, \quad \text{C} = \tfrac{15}{64} e^4.$$

And integrating

$$s = a(1 - e^2)(\text{A}\,l - \tfrac{1}{2} \text{B} \sin. 2l + \tfrac{1}{4} \text{C} \sin. 4l). \qquad [34]$$

No constant is necessary, because at the equator s and l vanish together.

The lengths of any two arcs of the meridian being given from measurement, to determine the polar and equatorial diameters.—If l and l' be the latitudes of the two extremities of the first arc, and s, s', their distances measured from the equator, then we have, from equation [34],

$$s = a\,(1 - e^2)\,(\text{A}\,l - \tfrac{1}{2} \text{B} \sin. 2l + \tfrac{1}{4} \text{C} \sin. 4l),$$
$$s' = a\,(1 - e^2)\,(\text{A}\,l' - \tfrac{1}{2} \text{B} \sin. 2l' + \tfrac{1}{4} \text{C} \sin. 4l').$$

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Taking the difference of these equations, and putting $s - s' = S$, $l - l' = \lambda$, $l + l' = L$, we have, from Trigonometry, $S = a(1 - e^2)(A\lambda - B \sin. \lambda \cos. L + \frac{1}{2} C \sin. 2\lambda \cos. 2L)$. In like manner we have, for the second arc,

$$S' = a(1 - e^2)(A\lambda' - B \sin. \lambda' \cos. L' + \tfrac{1}{2} C \sin. 2\lambda' \cos. 2L');$$

and since, in these two equations, the values of S, λ, L, S', λ', L', are all known from observation, the quantities a and e can easily be found, and the polar radius b from the expression $b = a\sqrt{(1 - e^2)}$.

If $b = a(1 - \mathfrak{a})$, the small fraction $\mathfrak{a}$ is called the *ellipticity* of the spheroid. Hence

$$a(1 - \mathfrak{a}) = a\sqrt{(1 - e^2)} = a(1 - \tfrac{1}{2}e^2 - \tfrac{1}{8}e^4);$$

$$\therefore \quad \mathfrak{a} = \tfrac{1}{2}e^2 + \tfrac{1}{8}e^4. \qquad [35]$$

If Q be put for the elliptic quadrant, measured from the equator to the pole, we have $l = \frac{1}{2}\pi$ in equation [34]; therefore

$$Q = \tfrac{1}{2}a(1 - e^2)A\pi = \tfrac{1}{2}\pi a(1 - \tfrac{1}{4}e^2 - \tfrac{3}{64}e^4). \qquad [36]$$

If the earth be cut by a vertical plane perpendicular to the meridian, the radius of curvature of this section, at the point where it cuts the meridian, is equal to the normal M R, Fig. 3234.—For, since the earth is supposed to be a solid of revolution, the direction of gravity always passes through the axis of the earth. If therefore we conceive the plumb line to be carried over an indefinitely small arc perpendicular to the meridian, its direction will intersect the axis at the same point R as before; and therefore R is the centre, and M R the radius of curvature of this arc. The value of M R is given in formula [26].

To find the radius of the curvature at any place, when the earth is cut by a vertical plane making an angle θ with the meridian.—Let P A p, Fig. 3235, be an oblate spheroid, formed by the revolution of the ellipse P A p about its minor axis P p. Let P M A be the meridian of the given place M, M N m any section passing through the normal M r, making an angle θ with the meridian; then it is required to find the radius of curvature of the section M N m at the point M.

From any point N in the arc M N m draw N S perpendicular to M m, and S Q also perpendicular to M m in the plane P A p. Let the plane N S Q cut the plane D N E drawn through N, parallel to the equator in the line Q N. Because M S is perpendicular to S N and S Q, it is perpendicular to the plane N S Q, and therefore the plane M A m passing through M S is perpendicular to the plane N S Q. And because the planes N S Q, D E N, are perpendicular to the plane M A m, their common intersection Q N is perpendicular to this plane; therefore N Q S, N Q D, are right angles. Let rS $= x$, S N $= y$, $\angle$ N S Q = A M N $= \theta$, $\angle$ S r A = Q S Z $= l$, then will

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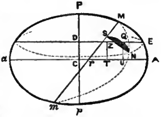

$$SQ = y \cos. \theta,\ SZ = SQ \cos. QSZ = y \cos. \theta \cos. l,\ QZ = SQ \sin. QSZ = y \cos. \theta \sin. l.$$

And because D E = D N, we have from the ellipse

$$a^2 b^2 = a^2 . CD^2 + b^2 . DE^2 = a^2 . CD^2 + b^2 (DQ^2 + QN^2). \qquad [a]$$

But
$$CD = ST - SZ = x \sin. l - y \cos. \theta \cos. l.$$
$$DQ = Cr + rT + TU = c + x \cos. l + y \cos. \theta \sin l.$$
$$QN = y \sin. \theta.$$

Making these substitutions in equation [a], it will be of the form

$$A x^2 + B x y + C y^2 + D x + E y + F = 0, \qquad [37]$$

where
$$A = a^2 \sin.^2 l + b^2 \cos.^2 l. \qquad D = 2 b^2 c \cos. l.$$
$$B = -2(a^2 - b^2) \sin. l \cos. l \cos. \theta. \qquad E = 2 b^2 c \cos. \theta \sin. l.$$
$$C = b^2 + (a^2 - b^2) \cos.^2 l \cos.^2 \theta. \qquad F = -(q^2 - c^2) b^2.$$

This is the equation to the ellipse, and we shall find the radius of curvature from the expression $\rho = \dfrac{d s^3}{d^2 x\, d y}$, dy being considered constant. Now, at the point M, $x = n$, $y = 0$, $\dfrac{dx}{dy} = 0$, $\dfrac{ds}{dy} = -1$; therefore $\rho = -\dfrac{dy^2}{d^2 x}$. Hence, differentiating equation [37] twice, we have

$$2 A x \frac{dx}{dy} + B y \frac{dx}{dy} + B x + 2 C y + D \frac{dx}{dy} + E = 0,$$

$$2 A x \frac{d^2 x}{dy^2} + 2 A \frac{dx^2}{dy^2} + B y \frac{d^2 x}{dy^2} + 2 B \frac{dx}{dy} + 2 C + D \frac{d^2 x}{dy^2} = 0;$$

and because $\frac{d\,x}{d\,y} = 0,\ y = 0$, we get $-\frac{d^2 x}{d\,y^2} = \frac{2\,\mathrm{C}}{2\,\mathrm{A}\,x + \mathrm{D}}$ and $\rho = \frac{2\,\mathrm{A}\,x + \mathrm{D}}{2\,\mathrm{C}}$; and since

$$\mathrm{A} = a^2 \sin.^2 l + b^2 \cos.^2 l = a^2 (1 - e^2 \cos.^2 l),$$

$$x = \mathrm{M}\,r = \frac{a\,(1 - e^2)}{\sqrt{(1 - e^2 \sin.^2 l)}},\ b^2 = a^2 (1 - e^2),\ c = \frac{a\,e^2 \cos.\,l}{\sqrt{(1 - e^2 \sin.^2 l)}};$$

$$\therefore\ 2\,\mathrm{A}\,x + \mathrm{D} = \frac{2\,a^3 (1 - e^2)}{\sqrt{(1 - e^2 \sin.^2 l)}},$$

$$\text{and}\quad \mathrm{C} = b^2 + (a^2 - b^2) \cos.^2 \theta \cos.^2 l = a^2 (1 - e^2 + e^2 \cos.^2 \theta \cos.^2 l);$$

$$\therefore\ \rho = \frac{a\,(1 - e^2)}{\sqrt{1 - e^2 \sin.^2 l}\,(1 - e^2 + e^2 \cos.^2 \theta \cos.^2 l)}. \qquad [38]$$

Cor. Because

$$\begin{aligned} &1 - e^2 + e^2 \cos.^2 \theta \cos.^2 l \\ &= (1 - e^2)(\sin.^2 \theta + \cos.^2 \theta) + e^2 \cos.^2 \theta \cos.^2 l \\ &= (1 - e^2) \sin.^2 \theta + (1 - e^2 \sin.^2 l) \cos.^2 \theta, \end{aligned}$$

We obtain from formula [38], $\frac{1}{\rho} = \frac{\sqrt{(1 - e^2 \sin.^2 l)}}{a\,(1 - e^2)}\ [(1 - e^2) \sin.^2 \theta + (1 - e^2 \sin.^2 l) \cos.^2 \theta]$.

And if r be the radius of curvature of the meridian at the point M, and r' the radius of curvature of a section perpendicular to the meridian, we have

$$r = \frac{a\,(1 - e^2)}{(1 - e^2 \sin.^2 l)^{\frac{3}{2}}},\qquad r' = \frac{a}{\sqrt{(1 - e^2 \sin.^2 l)}}.$$

Hence it follows that $\frac{1}{\rho} = \frac{\sin.^2 \theta}{r'} + \frac{\cos.^2 \theta}{r} = \frac{r \sin.^2 \theta + r' \cos.^2 \theta}{r\,r'}$;

$$\therefore\ \rho = \frac{r\,r'}{r \sin.^2 \theta + r' \cos.^2 \theta}, \qquad [39]$$

an elegant expression, which may be proved by the differential calculus to be true of all surfaces, when r and r' are the radii of greatest and least curvature of all sections passing through the normal at the point M.

To determine the figure of the earth from the vibration of pendulums.—This method, which is now very generally practised on account of its great facility, may be thus briefly explained. It appears from Mechanics that the time of vibration of a simple pendulum in a vacuum, when the arcs are indefinitely small, is determined by the equation $t = \pi \sqrt{\frac{\mathrm{L}}{g}}$. If, therefore, t and L be given, the value of g may easily be found. Let G represent the force of gravity at the equator, and g the force of gravity in any latitude l; then we have from Clairaut's theorem,

$$\frac{a - b}{b} + \gamma = \frac{5}{2} \cdot \frac{1}{289};\ \text{and } g = \mathrm{G}\,(1 + \gamma \sin.^2 l). \qquad [23]$$

Suppose now that a *pendulum*, of either of the forms described, is made to vibrate, and its vibrations are compared with those of the *pendulum* of a clock, as explained in the article PENDULUM, then if n be the number of vibrations which the clock pendulum makes between two successive coincidences, the experimental pendulum will make $n \pm 2$ vibrations. Let τ be the rate of the clock in seconds, or its gain in twenty-four hours, then the number of vibrations which the clock makes in a day is $24 \times 60 \times 60 + \tau = 86400 + \tau$. If therefore N be the number of vibrations made by the experimental pendulum in a day, we have, manifestly, $n : n \pm 2 :: 86400 + \tau : \mathrm{N}$; therefore

$$\mathrm{N} = \frac{n \pm 2}{n}(86400 + \tau) = 86400 + \tau \pm \frac{172800 + 2\,\tau}{n}. \qquad [40]$$

Let N′ be the number of vibrations which the same pendulum makes in any other latitude l', and g' the force of gravity at this place. We have then

$$\frac{\mathrm{N}^2}{\mathrm{N}'^2} = \frac{g}{g'} = \frac{\mathrm{G}\,(1 + \gamma \sin.^2 l)}{\mathrm{G}\,(1 + \gamma \sin.^2 l')} = 1 + \gamma\,(\sin.^2 l - \sin.^2 l'),$$

nearly, γ being a very small quantity; therefore

$$\gamma = \frac{\mathrm{N}^2 - \mathrm{N}'^2}{\mathrm{N}'^2 (\sin.^2 l - \sin.^2 l')}. \qquad [41]$$

The value of γ being determined in this manner from experiment, the ratio of a to b will be found from the first of equations [23].

In this investigation several corrections have been omitted which must be taken into consideration when great accuracy is required.

(1). *Correction for the amplitude of the arc of vibration.*—In the expression given for the time of vibration (see Pendulum), the arc is supposed to be indefinitely small. Let t be the observed time of vibration, ϕ the amplitude or semiarc of vibration, and t_1 the time of vibration, when the arc is indefinitely small; then we have $t = \pi \sqrt{\frac{L}{g}} \left(1 + \frac{\phi^2}{16}\right) = t_1 \left(1 + \frac{\phi^2}{16}\right)$. Hence if N be the observed number of vibrations made in a day, and N_1 the number in an indefinitely small arc, $\phi \, N_1 \, t_1 = 24$ hours $= N \, t$, therefore

$$N_1 = N \frac{t}{t_1} = N \left(1 + \frac{\phi^2}{16}\right). \qquad [42]$$

If therefore ϕ remains nearly constant during the time of observation, the number of vibrations N must be multiplied by the quantity $1 + \frac{1}{16} \phi^2$. But as the amplitude is continually diminishing on account of friction and the resistance of the air, it is necessary to make an allowance for this change. Now it is proved, both by theory and experiment, that the arcs decrease very nearly in geometrical progression. Let therefore ϕ be the first arc, ϕ' the last, and m the number of terms, which is always a very large number. Also, let q be the ratio of the square of each arc to the square of the preceding arc; then the whole time of vibration will be represented by the equation

$$T = \pi \sqrt{\frac{L}{g}} \left\{ m + \frac{\phi^2}{16} (1 + q^2 + q^4 \dots + q^{m-1}) \right\}$$

$$= \pi \sqrt{\frac{L}{g}} \left(m + \frac{\phi^2}{16} \frac{1 - q^m}{1 - q} \right).$$

Let $q = 1 - x$, then x is a very small quantity, and

$$\log. (1 - x) = M (- x - \tfrac{1}{2} x^2 - \&c.) = - M x, \text{ nearly},$$

M being the modulus in the common system of logarithms; hence

$$x = - \frac{\log. (1 - x)}{M}, \quad \text{or, } 1 - q = - \frac{\log. q}{M};$$

and since $q^{m-1} \phi^2 = \phi'^2$, we have

$$- \log. q = \frac{2 \log. \phi - 2 \log. \phi'}{m - 1} = \frac{2 (\log. \phi - \log. \phi')}{m}, \text{ nearly};$$

$$\therefore \quad 1 - q = \frac{2 (\log. \phi - \log. \phi')}{M \, m}.$$

Also, $$\phi^2 (1 - q^m) = \phi^2 - q \, \phi'^2 = \phi^2 - \phi'^2, \text{ very nearly}.$$

Making these substitutions in the expression for T given above, we have

$$T = \pi \sqrt{\frac{L}{g}} \left\{ m + \frac{M \, m}{32} \frac{\phi^2 - \phi'^2}{\log. \phi - \log. \phi'} \right\},$$

and therefore the mean time of one vibration is

$$t = \pi \sqrt{\frac{L}{g}} \left(1 + \frac{M}{32} \frac{\phi^2 - \phi'^2}{\log. \phi - \log. \phi'} \right), \text{ or } t = t_1 \left(1 + \frac{M}{32} \frac{\phi^2 - \phi'^2}{\log. \phi - \log. \phi'} \right).$$

Hence if ν_1 be the correction to be added to the observed number of vibrations N in a day, we manifestly have

$$\nu_1 = N \frac{M \sin.^2 1^\circ}{32} \frac{\phi^2 - \phi'^2}{\log. \phi - \log. \phi'}, \qquad [43]$$

the arcs ϕ and ϕ' being estimated in degrees.

(2). *Correction for temperature.*—When a pendulum is made to vibrate at different times, its length will vary with the temperature, and therefore the time of vibration will also vary; hence it is necessary to reduce the number of vibrations to a given standard (62°). Let T be the mean height of all the thermometers employed during the experiments, and e the rate of expansion of the metal for 1° of Fahrenheit, then if L, L′, be the lengths of the pendulum at the temperature of T°, and 62°, and N, N_2, be the corresponding numbers of vibrations in a day, we shall have $L = L' [1 + e (T^\circ - 62^\circ)]$, and consequently

$$\frac{N_2}{N} = \sqrt{\frac{L}{L'}} = \sqrt{1 + e (T - 62)} = 1 + \tfrac{1}{2} e (T^\circ - 62^\circ), \text{ nearly}.$$

Hence if ν_2 be the correction to be added on account of the increase of temperature,

$$\nu_2 = \tfrac{1}{2} N e (T^\circ - 62^\circ). \qquad [44]$$

(3). *Correction for the buoyancy of the atmosphere.*—When a body moves in a fluid its weight is diminished by the weight of an equal bulk of fluid, and therefore the accelerating force is diminished in the same proportion. Let N be the number of vibrations made in a day in air, N_3 ditto in a vacuum; g the force of gravity in air, g' ditto in a vacuum; σ the specific gravity of air, S that of the pendulum during the experiments; then

$$\frac{g'}{g} = \frac{S}{S - \sigma} = \left(1 + \frac{\sigma}{S - \sigma}\right), \text{ also } \frac{N_1}{N} = \sqrt{\frac{g'}{g}} = \sqrt{\left(1 + \frac{\sigma}{S - \sigma}\right)} = 1 + \tfrac{1}{2}\frac{\sigma}{S - \sigma}, \text{ nearly.}$$

Let h be the height of the barometer, and T the temperature of the air during the experiments: also let σ' be the specific gravity of the air at the temperature of 32°, when the barometer stands at a given altitude H, and h' the height of the same weight of mercury reduced to the temperature T. It appears, then, from hydrostatics that the specific gravity of the air

$$= \frac{p}{k\,[1 + a\,(T^\circ - 32^\circ)]},$$

when p is the pressure on a unit of surface, a is the expansion of air for 1° of temperature, and k is a constant quantity; hence $\sigma : \sigma' :: \frac{h}{1 + a\,(T^\circ - 32^\circ)} : h'$. Also, if μ be the expansion of mercury for 1° of temperature, $h' = H\,[1 + \mu\,(T^\circ - 32^\circ)]$. Substituting this value of h' in the proportion above, and forming an equation, we get $\sigma = \sigma' \frac{h}{H} \frac{1}{1 + (a + \mu)\,(T^\circ - 32^\circ)}$, very nearly.

According to MM. Arago and Biot, when $H = 29 \cdot 9218$, and the temperature is 32°, σ' is equal to $\frac{1}{770}$, therefore $\frac{1}{2} \frac{\sigma'}{H} = \cdot 0000217$. Also, $a = \frac{1}{450} = \cdot 00222$, $\mu = \cdot 0001$, and therefore $a + \mu = \cdot 0023$. Hence $\frac{1}{2}\,\sigma = \frac{\cdot 0000217}{1 + \cdot 0023\,(T - 32)}$, and $\frac{N_1}{N} = 1 + \frac{\cdot 0000217\,h}{(S - \sigma)\,[1 + \cdot 0023\,(T^\circ - 32^\circ)]}$; or if we put $\frac{1}{770}$ (= ·0013) for σ in the denominator, we shall have, for the correction to be added to N,

$$\nu_3 = N\,\frac{\cdot 0000217}{S - \cdot 0013}\,\frac{h}{1 + \cdot 0023\,(T^\circ - 32^\circ)}. \qquad [45]$$

See Algebraic Signs. Barometer. Distances. Gravity. Gunnery. Pendulum. Surveying. Thermometer.

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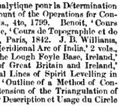
GERMAN SILVER. Fr., *Argentan*; Ger., *Neusilber*; Ital., *Packfong*; Span., *Plata alemana.*

See Alloys.

GIMBALS. Fr., *Balanciers du compas ou de la lampe*; Ger., *Bügel des Compasses order des Nachthauses*; Ital., *Snodo universale*; Span., *Aparato de suspension.*

A *gimbals*, Fig. 3236, is a contrivance for securing free motion in suspension, or for suspending anything, as a chronometer, ship's compass, marine barometer, &c., so that it may keep a constant position, or remain in equilibrium unaffected by the motion of connected bodies, or by the motion of a ship. It consists of a ring, Fig. 3236, within which the suspended body turns on an axis through the diameter, while the ring itself turns on another axis at right angles to the first, by means of pivots resting on an outer ring or other means of support. See Compass.

3236.



GIN. Fr., *Manége à malettes*; Ger., *Pferdegöpel*; Span., *Manija.*

A gin is a machine or instrument by which the mechanical powers are employed in aid of human strength; especially a machine consisting of a tripod formed of poles united at the top, one of them being longer than the rest and called the *pry-pole*, with a windlass, pulleys, ropes, &c., for raising or moving heavy weights, lifting ore from mines, hauling cannon, and like purposes.

A *gin* is also a machine for separating the seeds from cotton, called hence a *cotton gin.*

GIN, Carpentry. Fr., *Chèvre*; Ger., *Hebezeug*; Ital., *Capra*; Span., *Cábria de carpinteros*, or *Borriquete.*

See Elevators, Hoists, and Lifts.

GIN, Cotton Gin. Fr., *Machine égreneuse*; Ger., *Egrenirmaschine*; Ital., *Sgranatore*; Span., *Máquina para desmotar el algodon.*

See Cotton Machinery. Gin.

GLAND, of a Stuffing Box. Fr., *Chapeau d'une boîte à etoupes, Couronne de la presse-étoupe*; Ger., *Stopfbüchse*; Span., *Sombrerete de una caja de estopas.*

A gland is the cover of a stuffing box; sometimes called a follower. A cross-piece or clutch for engaging and disengaging machinery moved by belts or bands is also called a *gland.*

GLASS FURNACE. FR., *Four de verrerie*; GER., *Glasofen*; ITAL., *Vetriera*; SPAN., *Horno de vidrio.*

See GLASS MACHINERY.

GLASS MACHINERY. FR., *Machines de verrerie*; GER., *Maschinen zur Anfertigung des Glases*; ITAL., *Macchine da lavorare il vetro*; SPAN., *Maquinaria para la fabricacion de vidrio.*

Machinery for the Manufacture of Plate Glass.—G. H. Daglish, in the P. I. M. E., 1863, observed that within the last ten years the production of plate glass in England has been quadrupled, whilst in the same time the price has been diminished fully one-half. The present extent of the manufacture in this country is about 85,000 sq. ft. per week, whilst about 12,000 sq. ft. per week of foreign plate glass is imported. The foreign glass has obtained a preference from its superior lightness of colour, which arises from the greater purity of the materials that it is made of, particularly with regard to the sand, of which the foreign makers have an abundant supply, of great purity and light colour.

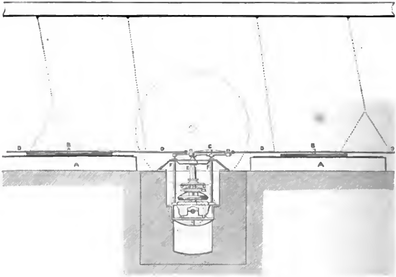
Under the influence of competition, the English manufacturers have lately commenced an extensive course of experiments with the view of improving the quality of the plate glass made in this country, and also reducing the cost of manufacture; and in some instances very decided success has thus far been the result. In order to accomplish these objects, the sand employed at the British Plate-Glass Works at Ravenhead, near St. Helen's, is now imported from France; and every precaution is adopted to ensure as far as possible the chemical purity of the other ingredients of the glass. Under these altered circumstances the glass now manufactured is equal in every respect to the best samples of the French production.

After the materials have undergone the process of melting in the furnace and are considered in a fit state for casting, the pot containing the melted mass is taken to the casting table, and its contents poured out on one end of the table, in front of a large cast-iron roller; the material is then spread over the surface of the table by passing the roller over it, the thickness of the plate of glass being regulated by strips of iron placed along each side of the table, on which the ends of the roller run. As soon as the plate of glass is sufficiently solidified to bear removal, it is introduced into an annealing oven, there to be gradually reduced in temperature or annealed, until it is fit to be exposed to the atmosphere without risk of fracture. This process of annealing used formerly to occupy upwards of a fortnight, but from the improved arrangement and construction of the annealing oven it is now completed in four days; thus three times the quantity of glass can now be annealed in each oven compared with what was formerly considered possible; and consequently a large outlay in building and in space has been saved, since only one layer of plates can be placed in the oven at one time, no method of piling the plates being considered practicable or even safe. The chemical difficulties and manipulation in producing the raw material have thus been very satisfactorily overcome; but the problem of carrying out the necessary improvements in the subsequent mechanical operations has not perhaps been so completely solved.

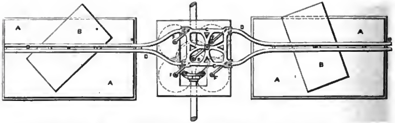
The plates of glass when taken from the annealing ovens are exceedingly irregular, particularly on the surface which has been uppermost in the process of casting, that surface being undulated or wavy after the passage of the roller over it whilst in a semi-fluid state; the lower side too is affected by any irregularities on the surface of the casting table, and also to some extent by the floor of the annealing oven; and both sides of the plates are also covered with a hard skin, semi-opaque. The plates vary in size, the largest being about 17 ft. long by 9½ ft. wide; and the thickness varies according to the size from ⅜ to ⅝ in. The first process to which the plates are submitted is that of grinding, to take off the hard skin and reduce the surface to a uniform plane, which is performed by the application of sand and water. The second process is that of smoothing, which is a continuation of the first process, but performed with emery of seven different degrees of fineness, so as to prepare the surface of the glass for the final process of polishing. This last process is effected by the use of oxide of iron employed in a moist state.

The machine in general use for grinding is that which was originally employed at the commencement of the glass manufacture, and is believed to have been designed by James Watt. It is known by the name of the fly-frame machine, and is shown in side elevation and plan in Figs. 3237, 3238. It consists of two benches of stone A A, sufficiently large to hold a plate of glass, and placed about 12 ft. apart: on these benches the plates of glass are fixed by plaster of Paris, as shown by the black line in Fig. 3237. Each bench has a runner-frame B made of wood, about 8 ft. long by 4½ ft. wide, shod on the under-side with plates of iron about 4 in. broad and ½ in. thick, and provided with a strong wrought-iron stud on the upper side, by which it is moved about over the surface of the glass. The gearing for driving these two runner-frames B is placed between the two benches, and consists of the square cast-iron fly-frame C, with two flat bars D hinged to it on opposite sides, extending over each bench A, and suspended from the roof by long chains, as shown by the dotted lines in Fig. 3237, so as to allow them to radiate freely in every direction; this is called the fly-frame from the peculiar motion given to it, and each of the runner-frames is connected to it by the central stud B, Fig. 3237, working loosely in the slot between the bars D. The fly-frame receives its motion from an upright spindle E, which is driven from the main line of shafting by a pair of bevel-wheels with a friction clutch for throwing in and out of gear. On the top of the spindle E is a wrought-iron arm or crank carrying a movable stud, which works in a bush in the centre of the fly-frame C. Round the centre spindle E are also four other spindles F, equidistant from the centre spindle and from one another, each carrying on the top a wrought-iron arm or crank with movable stud similar to the centre one; these studs severally work in bushes at each corner of the fly-frame. Hence when motion is given to the centre spindle E, the fly-frame C is carried round by the stud on the crank-arm, while its sides are always kept parallel to their original position by the four corner cranks F. The two runner-frames B, being connected by their central stud to the arms D of the fly-frame, receive the same circular motion as the fly-frame; but at the same time they are left free to revolve round their own centres, which they do in a greater or less degree according to the varying friction of the grinding surfaces. The grinding motion being thus obtained, sand and water are constantly applied, until the surface of the glass is found upon examination to be free from all defects; the sand is then washed off the glass, and the first stage of the smoothing process is commenced on the same machine by substituting the coarser qualities of emery in place of the sand. The plate of glass is then removed from the bench, turned over, and replaced on the bench, and submitted to the same process on the other side. The speed at which the fly-frame is driven is about forty revolutions per minute. It will be seen that the runner-frame B, Fig. 3238, is not sufficiently large to act upon the entire surface of a large plate of glass at one time; it is therefore necessary to divide the operation and shift the position of the runner-frame as the work requires it, by inserting the centre stud of the runner-frame into a different portion of the slot between the fly-frame bars D.

3237.

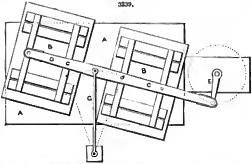


3238.



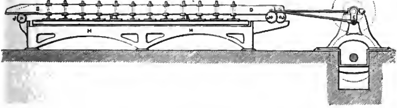
Until the last few years the principal part of the operation of smoothing was effected by manual labour, the operation being performed by rubbing two pieces of glass together, and applying emery powder between them. Great care is requisite as the work approaches completion that no scratching shall take place; and it is on this account that hand labour is considered absolutely necessary for finishing the process, the slightest scratch being immediately felt by a practised hand, whilst a single stray particle of grit on a machine would spoil the whole surface before it was perceived. About 1857 Crossley introduced a machine for smoothing the plates of glass, which so far succeeded that the nicety of the hand touch is only required for the final part of the operation. This smoothing machine, shown in plan in Fig. 3239, is exceedingly simple and inexpensive, consisting of a long wooden bar C, connected at one end to a crank E on an upright spindle, and extending over the stone bench A, on which the plate of glass is laid; two runner-frames B of wood are attached to the bar C, and on the under-side of each frame is fixed another plate of glass; these are then laid upon the glass on the bench. In this case the runner-frames B are only allowed to partake of the motion given to them by the bar, and are not left free to revolve round their own centres as in the grinding operation previously described. The centre of the bar C between the two runner-frames is kept in position by a radius rod G secured to a fixed bracket on one side of the bench, at right angles to the direction of the bar. The crank E being set in motion, the bar and runner-frames receive a movement somewhat similar to the figure 8, which is very similar to the motion given in manual labour. One advantage of this machine is that two surfaces of glass are finished at one operation. The space between the two runner-frames B is found very convenient for applying the emery, and also ascertaining the progress of the work, without having to stop the machine.

3239.

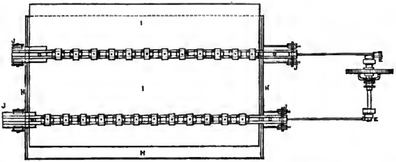


The machinery used in the polishing process remains the same in principle as that originally constructed for the purpose. Each machine consists of a strong cast-iron frame H, Figs. 3240, 3241, about 18 ft. long by 10 ft. wide, containing a series of small rollers, upon which is placed a

3240.



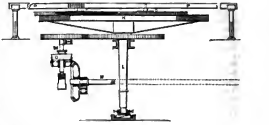
3241.



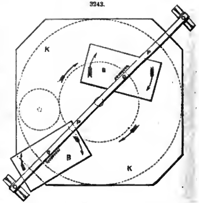
wooden table I, with two racks on the under-side; suitable gearing is connected to these racks, to give the table a slow alternate lateral motion so as to bring every part of the plate of glass under the action of the rubbers B. The plates of glass are fixed upon the table I by plaster of Paris, and the ends of the table move between slide-blocks secured to the main frame H, so as to prevent the action of the rubbers from displacing it. The rubber-blocks B are pieces of wood covered with felt, and provided with a central spindle and adjustable weights to regulate the amount of friction. A number of these blocks are secured to two movable bars D, running on rollers J J at each end of the table I, and driven by a short shaft E, with cranks at the ends set at right angles to each other. The rubber-blocks are thus worked transversely to the motion of the table; and by applying the polishing powder in a liquid state the surface of the glass is gradually brought up to the requisite degree of polish, both sides of the plate successively being subjected to the same operation.

About 1857 experiments were commenced at the British Plate-Glass Works at Ravenhead, with an entirely different class of machinery for grinding and smoothing plate glass, with the object of increasing the production, reducing the cost, and also completing the process of smoothing upon the same machine on which the glass is ground, so as to obviate the necessity of a separate machine for smoothing, and also save the expense and loss of time in removing and refixing the plates of glass. The new grinding and smoothing machine is shown in Figs. 3242, 3243, and consists of a revolving table K, 20 ft. diameter, fixed upon a strong cast-iron spindle L, and running at an average speed of twenty-five revolutions per minute, driven through an intermediate upright shaft M, from the main line of shafting N, by a pair of bevel-wheels, and friction cone O for throwing in and out of gear. This arrangement of gearing for driving the table was made by G. H. Daglish, and was adopted in order to obtain a long spindle L for the table, of a length equal to the semi-diameter of the table, and at the same time to keep the main line of shafting N continuous, for driving a series of tables in one room. Over the top of the table a strong timber bar P is fixed, about 10 in. from its surface; and on the two opposite sides of this bar are bolted two notched plates of cast iron, Q, one on each side of the centre of the table. The notches are for receiving the centre studs of the runner-frames B, which are very similar to those used on the old class of machinery; and the runners can thus readily be moved nearer to or farther from the centre of the table, as circumstances require, by shifting the stud into a different notch. The only motion which these runner-frames have is round their own centres, and this is given to them by the excess of friction on the side farthest from the centre of the table over that on the side nearest to the centre, this excess being caused by the greater velocity of the portion of the table farther from the centre. It is evident that the amount of grinding action is considerably greater on this machine than upon the old one, both from the increased velocity of the runner-frames themselves, and also from the double amount of movement obtained by the revolution of the table K and the runner-frames B. The idea of driving the runner-frames themselves, as well as the table, was conceived at an early stage of the experiments; but on being put to the test, it was found that the unaided movement of the runner-frames adapted itself to the work to be performed far better than any compulsory motion could do. It has also the advantage of leaving the surface of the table free and unencumbered with any machinery, and consequently facilitates the operation of laying and removing the plates of glass: the whole of the driving machinery is also covered over, and thus protected from the injurious effects of the sand and water thrown off from the edge of the table in working.

3242.



3243.



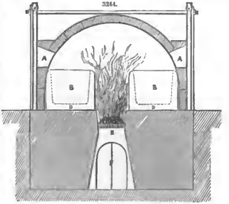
This machine has been found to answer equally well for smoothing as for grinding; and this is perhaps its most successful feature in a commercial and economical point of view. Both these processes are now completed on it at the Ravenhead Glass Works, the finishing portion of the smoothing operation alone being effected by manual labour for the reasons before stated. The plates of glass being generally oblong in form, it was found that the machine in its original shape, having a circular table K for carrying the glass, as shown by the dotted circle in Fig. 3243, entailed considerable waste in filling up the area of each table for grinding; and it was then determined to alter the shape to that of an unequal-sided octagon, or square with the corners taken off, as shown in the plan, Fig. 3243. No difficulty has been experienced in the process of grinding from this alteration in form, whilst the amount of waste in making up the tables has been considerably reduced, and greater facilities are obtained for grinding large plates. The amount of wear and tear on this machine has been found to be very small in comparison with the old machines, owing to the small number of working parts, the large extent of bearing surface, the smoothness of the motion, and the complete balancing of the table. The quantity of glass finished upon one of these machines a week is from 1200 to 1500 sq. ft., which is about one-third more than the old machines are capable of doing, due allowance being made for the difference of area.

The Mechanical Appliances employed in the Manufacture of Polished Sheet Glass.—Richard Pilkington, jun., observed, in the Proceedings of Inst. M. E., 1863, that the manufacture of British sheet glass was introduced into England about the year 1832, by Messrs. Chance Brothers, of Birmingham. Since then it has become generally used, having almost superseded crown glass, in consequence of the comparative ease of obtaining the large squares at present required for windows, and the absence of wave lines by which the vision is so much distorted in crown glass. The average size of sheet glass is 40 in. by 30 in., but if required it can be made much larger; whilst with crown glass it is almost impossible to procure a square as large as 34 in. by 22 in. Sheet glass, when used for windows, has generally a peculiar appearance when viewed from the outside of a building, on account of the unevenness of its surface, an eyesore partially obviated by the improved method of flattening, but entirely removed when the glass is polished. When polished it is known by the name of patent plate, to distinguish it from British plate. This polished sheet plate has a decided preference over British plate, being harder and more difficult to scratch, besides taking a higher polish; it is also cheaper.

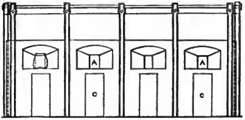
The manufacture of polished sheet glass consists of the three following processes;—1st, melting and blowing; 2nd, flattening; and 3rd, polishing.

1. *Melting and Blowing.*—Two furnaces are required, one for melting the materials or frit, and the other for reheating the metal whilst blowing it into a cylindrical form. The melting furnace is a reverberatory furnace, arranged for maintaining a high temperature with great uniformity and freedom from dust or other impurities arising from the fuel. The furnace, an eight-pot one, is shown in Figs. 3244, 3245. There are four gathering holes, or working holes A A on each side of the furnace, as shown in the side elevation, Fig. 3245, each of the eight pots B having a working hole. The temporary brickwork C beneath each working hole can be removed when required, either to turn a pot or whilst fixing a new one. A raised bed D extends the entire length of the furnace, upon which the pots are placed on each side of the fire-grate. The fire-grate E extends the entire length of the furnace, with the exception of a space of about 4 ft. in length, and is fed from each end of the furnace. The air is supplied through the underground passage F, entering from the open air; and by means of closely-fitting doors the draught is regulated with great nicety.

3244.



3245.



Formerly it was considered necessary to use stone for the melting furnaces, but at the present time large bricks made of best fire-clay have a decided preference. These fire-bricks vary in weight from a few lbs. to several cwts.; they are all made in moulds, dried, partially burnt, accurately dressed to templates, and built into the furnace, the whole being firmly secured by cast and wrought iron binders, as shown in Figs. 3244, 3245. A small fire is lighted upon the fire-grate, and gradually increased, first to dry the furnace, and afterwards to bake it. Great care and attention are given to this operation, for upon it depends the duration of the furnace. After being baked the furnace receives its number of pots, generally four or five on each side of the fire-grate, in all eight or ten pots. The manufacture of these pots is a matter of special importance, and they are made of the very best Stourbridge fire-clay, which, when thoroughly tempered, is formed into rolls of about 1 lb. weight each, and worked layer upon layer into a solid mass, free from cavities containing air, and making a pot of about 4 ft. height inside, 5 ft. diameter at top, and about 4½ ft. diameter at bottom inside, weighing when dried about 25 cwt., and containing about 22 cwt. of melted metal. Great care is requisite to prevent any particles of foreign matter or dirt from getting into the clay; for if that were to happen, the pot would not last its time, but would most likely give way when first heated to the working temperature. After being made, a pot remains in the same room for a year, the temperature being maintained at 60° Fahr., and it is then removed to a warmer room, where it remains in a temperature of 90° until it is wanted. When required for use, it is taken to the pot-arch to be baked, where the heat is gradually increased to that of the melting furnace, to which it is conveyed whilst red hot, as quickly as possible, by means of a carriage or a crowbar on wheels, and placed on one side of the fire-grate. This operation is repeated until all the pots are fixed in the melting furnace. The furnace ends are now closed, with the exception of the fire-hole at each end. A small portion of cullet, or broken glass, is put into each pot, and when melted is ladled so as to run down over the interior surface of each pot, after which the heat is increased for a short time. The pots are thereby glazed, and are now ready to receive the material to be melted.

The quantity of raw material, or frit, allotted to each pot is filled into it in three or four charges, allowing a sufficient interval of time to elapse between each charge to ensure the previous one being melted. About sixteen hours of intense heat are required to melt the entire quantity, during which time the fluid metal boils violently, and before it can be worked requires cooling, which takes about eight hours. Whilst cooling, the small bubbles of air arising from the boiling of the metal ascend and pass away, leaving the metal clear, excepting the surface, which is coated with impurities from the frit, from the roof of the furnace, and from the dust of the fuel, all of which must be removed before commencing work. Inside each pot, and floating upon the surface of the metal, is an annular ring, made of fire-clay, 2 in. thick, having an internal diameter of 18 in.; this inner space of 18 in. diameter is cleaned, instead of the entire surface of the metal, thereby saving both time and material. The cleaning or skimming is performed by means of a light iron rod, chisel pointed, which being warmed the metal adheres to it; and this process is repeated whenever any impurities are perceived upon the surface of the metal. The surface of the melted metal being cleaned, the workman dips into it the blow-pipe, Fig. 3246, having previously warmed the nose end of the pipe. Withdrawing 2 or 3 lbs. of the metal, he allows it to cool to a dull red, and then dips the pipe again; collecting by degrees in this way, as shown in Fig. 3247, a sufficient quantity to produce a given-sized sheet of glass, which on the average would weigh about 20 lbs. Then, while cooling the pipe he continually turns it round, drawing it towards himself, and in so doing forces the metal beyond the nose end of the pipe by means of the forked rest in which the pipe revolves, as shown in Fig. 3248, leaving as little metal as possible upon the pipe. The blower now takes the pipe, and places the red-hot mass in a hollowed wooden block upon the ground, Fig. 3249, keeping the pipe in a horizontal position whilst revolving it, thereby producing a solid cylindrical mass of metal. During this process his assistant allows a fine stream of cold water to run into the block from a sponge, keeping the wood from being burnt, and giving a brilliant surface to the glass. He next raises the pipe to an angle of about 75°, and blows until he has produced a hollow pear-shaped mass, Fig. 3250, with its largest diameter the same as that of the finished cylinder. During this operation his assistant keeps the block wet, and a second block is generally used when commencing the blowing. The glass now requires reheating, which is done at a furnace built of ordinary brickwork in an oblong form, its dimensions being determined by the number of blowers intended to work at it, generally four, five, or six at each side. The ground at each side of this furnace is excavated to a depth of about 7 ft., a width of about 16 ft., and the same length as the furnace; and over each of these spaces four, five, or six wooden stages are erected, at distances of about 2 ft. apart. Having reheated the glass, the blower repeatedly blows to maintain the cylinder of equal diameter throughout, whilst lengthening it by swinging it backwards and forwards in the 2-ft. space, and occasionally swinging it round over his head, until a cylindrical piece of glass is produced, Fig. 3251, about 11 in. diameter and about 50 in. long, closed at one end, and having the blow-pipe attached to the other end. The blower first opens the closed end as follows: enclosing as much air as possible within the cylinder, and stopping the mouthpiece of the pipe with his hand, he exposes the end of the cylinder to the heat of the furnace, which, whilst softening the glass at the end, expands the contained air to such an extent that a small hole is burst in the glass, as in

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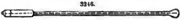

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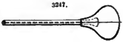

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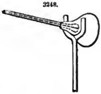

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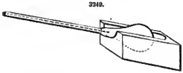

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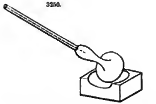

3251.

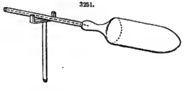

Fig. 3252. This hole is flashed open by revolving the pipe quickly, and when flashed the end of the cylinder is withdrawn out of the furnace; and by keeping the pipe in a vertical position for a few seconds, the metal cools sufficiently to keep its shape. The cylinder is then placed upon a wooden trestle, and by touching with a piece of cold iron the pear-shaped neck near the pipe-nose at G in Fig. 3252, a crack is formed, which is continued round the neck by gently striking the blow-pipe, and thus the pipe is released, as seen in Fig. 3253. The cylinder has now one end of full diameter, but the other is contracted to about 3 in. diameter, Fig. 3253, and must therefore be cut off. This is accomplished as follows;—The cylinder having become cold whilst remaining on the trestle, the workman collects a small portion of metal upon the end of an iron rod, and draws it into a thread of glass about ¼ in. diameter by means of a pair of pincers. This thread he passes round the body of the cylinder at H H, in Fig. 3253, and after it has remained on a few moments the pincers dipped in cold water are applied to the heated part, and the sudden contraction causes the end to fly off with a sharp report, leaving the cylinder about 45 in. long and 11 in. diameter.

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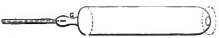

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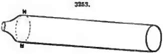

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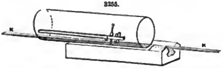

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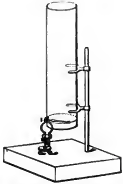

2. *Flattening.*—To produce a flat sheet of glass from the cylinder thus obtained forms the second process of the manufacture. The flattening is accomplished as follows;—The end of the cylinder that was flashed being slightly contracted in diameter, and the thickness of metal much reduced, it is first necessary to cut off about 2 in. length from that end. For this purpose the cylinder is supported in a vertical position by means of a cradle, as shown in Fig. 3254, over a small horizontal table; the bottom edge of the cylinder is introduced between the jaws of the small cutting instrument I, and the movable jaw carrying the cutting diamond is pressed by a spring against the interior surface of the cylinder; then by gently pushing the instrument forwards round the cylinder, allowing it to run freely upon its wheels, the end of the cylinder is cut off perfectly true. The cylinder then requires splitting longitudinally, which is accomplished by placing it in a horizontal position in a wooden cradle, as shown in Fig. 3255, and a diamond fixed in the cleft of a stick at J is drawn along inside the cylinder from end to end, guided by the straight-edge K, a gentle pressure being exerted on the glass in opposite directions, at the diamond cut, to complete the splitting.

The cylinder is now taken to the flattening kiln, Fig. 3256, which consists of two furnaces built together, the first, L, for flattening, and the other, M, for annealing, the former being maintained at a much higher temperature than the latter. A portion of the bottom of the flattening kiln L, slightly larger than the largest sheet of glass to be flattened, is supported upon a carriage N, which with the flattened sheet is made to travel into the annealing kiln M, this plan being a very great

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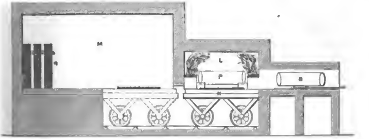

improvement over the old method of pushing the flattened sheet whilst in a soft state. The movable bed N is either of clay or stone, and by careful work is made as true as possible; upon this a sheet of glass is first flattened and left there to flatten others upon, in order to obtain sheet glass with as true a surface as possible. The split cylinder to be flattened is gradually introduced into the flattening kiln, being placed first at O and then at P, and when sufficiently warmed is placed upon the glass bed N, with its split side uppermost; the heat soon softens it, so that with a slight assistance from the workman it lies down nearly flat on the bed N, and the sheet is afterwards carefully rubbed as flat as possible with a piece of wood fixed to the end of an iron rod. The movable bed N is now pushed forwards into the annealing kiln M, as shown by the dotted lines, and after placing another cylinder to warm at O and P, the workman removes the flattened sheet from the carriage N by means of a tool like a fork, and places it upon a prepared part of the floor of the annealing kiln M, to stiffen previous to piling it. The carriage N is now returned to the flattening kiln L, and the flattening operation repeated till the carriage again appears in the annealing kiln M. The previously-flattened sheet is first piled on its end against one side of the kiln at R, and then the last flattened sheet is removed off the carriage N, and left to cool on the floor of the annealing kiln, like the previous sheet. This flattening process is continued until the annealing kiln M is filled, when it is closed up, and allowed to cool, generally from twenty-four to thirty-six hours, the time being regulated by the thickness of the glass. On the completion of the cooling, the kiln M is opened, and the sheets of glass are taken to the warehouse, where they are sorted to suit various purposes, a very large portion being packed and sent away without undergoing any further process.

3. *Polishing.*—The sheets intended to be polished are now selected, and pass through the third process of the manufacture to produce polished sheet plate. Two processes are necessary for this purpose, smoothing and polishing.

Smoothing consists in working two sheets of glass one upon the other, by hand, with emery and water between them; and as their surfaces become obscured, finer and finer *emery* is used until the surfaces are smoothed free from all defects. The apparatus used consists of a wooden bench, one half of which is 6 in. higher than the other; upon the former is placed a slab of slate about 1½ in. thick, larger than the sheet of glass, having as true a surface as possible. Upon this slab a sheet of glass is laid, with a piece of wet calico between the surfaces of the glass and the slab; by exerting a gentle pressure upon the glass the air is expelled from between them, and the sheet of glass is consequently held down upon the slab by the whole atmospheric pressure upon its surface, which holds it so firmly that when the sheets have to be raised from the slab many are broken, even by experienced workmen. The wet calico is used in this case instead of plaster of Paris for bedding the sheet of glass upon the table. In consequence of the close adhesion caused by the atmospheric pressure when the surfaces of the two sheets of glass get so true as to become closely in contact, it is impossible to work two large sheets one upon the other with the finest emeries, and it therefore becomes necessary to perform the latter portion of the rubbing process with a small piece of glass, say about 10 in. by 5 in., until the process is completed. Both sides of the sheet of glass having been smoothed in this manner, and after a careful examination found free from defect, the sheet is then handed over to the polishing machine.

The perfection of the smoothing process is entirely dependent upon the purity of the emery, and the perfect uniformity of the grain in each successive quantity employed; and consequently a very perfect process of cleansing and sorting the emery is requisite. The ordinary ground emery contains, besides numerous degrees of fineness of grain, many impurities, which must be removed, and the good emery must also be accurately sorted into portions varying in size of grain from coarse to the finest. For every degree of fineness a separating vessel or cylinder is required; and taking No. 1 as the coarsest quality, that cylinder is made the smallest in the series, No. 2 cylinder about twice the capacity of No. 1, and No. 3 twice the capacity of No. 2; and so on throughout the required number of cylinders. The emery-sorting apparatus is shown in Fig. 3257, and consists of the required number of cylinders, fixed so that No. 1 cylinder is about 3 in. higher than No. 2, and No. 2 the same height above No. 3, and so on. The cylinders are made of copper, and inside each is fixed a copper funnel S, long enough to reach within 3 or 4 in. of the bottom of the cylinder; and in the bottom of the cylinder is a hole closed by a wooden plug, or a valve T, of about 3 or 4 in. diameter, which is held up by the rod and spring balance U. The action of the apparatus is as follows;—A supply of water being maintained by the cistern V, a constant stream is delivered by means of the tap W into the funnel of No. 1 cylinder; the water descends through this funnel to the bottom, and ascends through the annular space to the top of the cylinder, whence it is conveyed by the spout X and poured down the funnel of No. 2 cylinder, ascending in the annular space of No. 2, and passing by the spout to No. 3 funnel; this is repeated as often as there are cylinders, and from the last and largest cylinder the overflow is carried to a drain. When the stream of water is running through all the cylinders, and also passing away at the overflow, the powdered *emery* to be cleansed and sorted is sprinkled into the funnel of No. 1 cylinder, and this is continued until enough has been fed to fill up to within ½ in. of the bottom of the funnel. No. 1 being the smallest cylinder, the current of water through it will be the fastest, and the grains of emery left behind in this cylinder will consequently be the coarsest. The feeding of the emery is then stopped for a short time, and the stream allowed to continue until the water is running quite clear into the funnel of No. 2 cylinder. The valve T at the bottom of No. 1 cylinder is now opened, allowing the emery and water to fall into a vessel placed beneath to receive it; and as soon as the stream of water is again running through all the cylinders and passing away at the overflow, more emery is again sprinkled into No. 1 funnel. The succeeding cylinders are emptied in the same way, as they respectively become filled with the finer sorts of emery. The beauty of this process is the simplicity of apparatus required, and the certainty of always obtaining an exact repetition of the several degrees of fineness in the respective cylinders. It will be observed that, in consequence of the cylinders increasing successively in capacity, the current of water ascending in the annular spaces decreases in velocity in the same proportion; consequently, the emery deposited in each successive cylinder increases in fineness over that deposited in the previous one.

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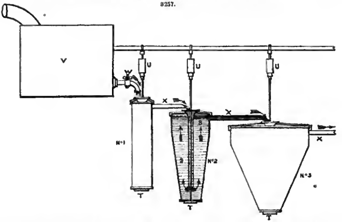


The polishing benches have two bars carrying the polishing blocks, and working lengthways backwards and forwards over the table on which the sheet of glass is laid, which is made to travel alternately from side to side, transversely to the bars. The polishing blocks are worked at about sixty double strokes per minute, and the bars carrying them are supported upon rollers at a height of 6 or 8 in. above the table. The moving table is worked similarly to the table of a planing machine, moving one way quicker than the other by a reversing motion similar to that of a planing-machine bed. It is generally considered that to obtain a good polished surface the polishing blocks should not pass twice in succession over the same surface. Upon the moving table are fastened slabs made of a wooden frame covered with slates, upon which the sheets of glass to be polished are bedded in plaster of Paris. After one side has been polished, the glass is taken up and relaid, and the other side polished. The polishing blocks are about 5 in. square, covered with felt, and weighted with about 84 lbs. each. The red liquor used in polishing is red oxide of iron, obtained by burning sulphate of iron in a reverberatory furnace to a dark red when cold, and it is then ground in water to the finest grain possible. The cutting grain of this material is about the hardest and finest that can be produced, and well worth examination by the microscope.

The appellation of *glass* is given to hard substances endowed with a certain degree of transparency, and presenting a peculiar kind of fracture called *vitreous*. In this point of view, many fusible substances which, on cooling, do not crystallize easily, such as phosphoric and boracic acids, should be classed among the *glasses*; but in common parlance the name *glass* is exclusively applied to double transparent silicates, which are worked when hot by blowing, and which are unchangeable in water. Glass is generally composed of a double silicate of lime and potassa or soda. In many kinds, as in bottle glass, the alkaline silicates are partly replaced by very fusible metallic silicates, such as the silicates of iron; in some, oxide of lead is also substituted for the lime. This last kind bears the name of *crystal*.

Before treating of the properties and composition of the various kinds of glass used in the arts, it is necessary to examine, more in detail than we have hitherto done, the properties of the simple silicates which enter into its composition.

Alkaline Silicates.—The only silicates used in the manufacture of glass are the silicates of potassa and soda, the most fusible of all the silicates; their degrees of fusibility greatly varying, however, with the proportion of the base. In order to express clearly the composition of the simple or multiple silicates, the ratio existing between the oxygen of the silicic acid and that of the united bases is generally indicated, as well as the proportion of the quantities of oxygen contained in the several bases. If silicic acid is fused with two or three times its weight of potassa or soda, a substance is obtained apparently homogeneous, melting at a red heat, and completely soluble in cold water. Silex, fused with an equal weight of potassa or soda, also produces a homogeneous substance, readily fusible, but no longer completely soluble in water. As the proportion of alkali diminishes, the vitreous mass becomes more difficult of fusion: an alkaline silicate, in which the oxygen of the alkali is to that of the silicic acid as 1 : 18, fuses only at the highest temperature of a forge-fire.

Soluble glass is a vitreous product obtained by melting together, in an earthen crucible, 15 parts of sand, 10 of carbonate of potassa, and 1 of charcoal. This substance, treated with cold water, parts only with the foreign salts which were mixed with the carbonate of potassa, but is itself completely dissolved in four or five times its weight of boiling water. It has been proposed to use this substance to render cloth, and particularly theatrical decorations, incombustible. In Germany, this combination, known by the name of *wasserglas*, a large manufactory of which is at Prague, is extensively employed for rendering especially the wooden work of buildings incombustible, and protecting them at the same time from decomposition (rotting). In England it is used for the same purpose, made up with various pigments, as *silica colours*. It probably would also make an excellent artificial marble, capable of being moulded into architectural ornaments, or spread as a plaster on walls, when made up with proper proportions of porcelain clay, or, perhaps, even chalk or plaster of Paris, with a slight admixture of borax. It was first obtained by Fuchs, at Munich. In fact, if a coat of this solution be applied to any stuff, it remains covered, after drying, with a transparent and fusible varnish, which preserves it from the air; and it burns with difficulty, because the silicate prevents the access of the air. The stuff merely carbonizes, and does not favour the progress of the fire, as would be the case if its surface were free. Many fusible and non-efflorescent salts, among which are the phosphate and borate of ammonia, would produce the same effect. The silicates of potassa and soda are distinguished by the property of not crystallizing on cooling after fusion, owing to their passing from the state of perfect liquidity to that of a solid, not suddenly, but through all the intermediate doughy conditions. This property accompanies the alkaline silicates in their combination with the other metallic silicates, and is very important, as it facilitates the working of these multiple silicates by blowing; and, moreover, the substance retains its transparency after cooling.

Silicates of Lime.—The silicates of lime melt at only very high temperatures. The most fusible compound is that resulting from the union of silicic acid with lime, in such proportions that the oxygen of the lime is to that of the silicic acid as 1 : 3; this silicate melts in a strong forge-fire, and becomes crystalline on cooling. The silicates of lime, having a ratio of 1 : 4 or 1 : 1 between the oxygen of the base and that of the acid, do not fuse completely, only softening in the highest heat that can be produced in a forge-fire.

Silicates of Magnesia.—The silicates of magnesia are as difficult of fusion as those of lime. The most fusible is that of which the formula is MgO, SiO_3; it melts in a strong forge-fire.

Silicates of Alumina.—The silicates of alumina are still more infusible than those of lime and magnesia. The silicate $Al_2O_3, 3SiO_3$, which appears the most fusible, merely softens in a forge-fire. All these silicates melt easily in the oxyhydrogen blow-pipe; for we know that alumina and silex melt separately in the powerful heat produced by this apparatus.

Silicates of the Protoxide of Iron and Manganese.—These silicates, which enter into the composition of some kinds of glass, melt much more readily than the silicates of the earths and those of the alkaline earths. The silicates FeO, SiO_3 and MnO, SiO_3 may be melted in the common furnaces of our laboratories; they all crystallize easily by slow cooling.

Silicates of Lead.—The silicates of lead are fusible in proportion to the quantity of oxide of lead they contain; that showing the composition PbO, SiO_3 melts at a strong red-heat. The silicates of lead crystallize with difficulty; the cooling must take place very slowly, in order to obtain any indices of crystallization in the mass.

Multiple Silicates, formed by the Alkalies, the Alkaline Earths, the Earths, and Metallic Oxides.—Several multiple silicates, in the form of beautiful crystals, are found in nature. We know that feldspar is a double silicate of alumina and potassa, of the formula $KO, SiO_3 + Al_2O_3, 3SiO_3$. This mineral melts in a forge-fire, and does not crystallize during the very slow cooling of a porcelain furnace; but crystals of this compound have been found in the fissures of iron blast-furnaces, showing the same form as those of native feldspar. When the alkaline silicates are melted with other metallic silicates, vitreous substances are generally obtained after cooling, which appear homogeneous, and crystallize only when the cooling is extremely slow. But it is difficult to decide whether these substances are formed by a homogeneous chemical combination, or whether they merely result from a solution of various silicates in each other; a solution which has set in mass, without crystallizing during the process of cooling. The temperature at which a multiple silicate fuses is almost always below the medium temperature of fusion of the various simple silicates which compose it; sometimes it is even below that of the most fusible silicate entering into the combination. Thus, the simple silicates of alumina and lime are nearly infusible in our forge-fires, but they form, when combined, double silicates which readily melt in these fires. By adding to a silicate which crystallizes easily on cooling one which has not this tendency, for example, an alkaline silicate, double silicates are obtained, which crystallize with great difficulty, and preserve their vitreous appearance after cooling. Thus, the double silicates of potassa or soda, combined with those of lime or oxide of iron, do not crystallize after fusion. Silicate of alumina likewise opposes the crystallization of the multiple silicates into which it enters, although less effectually than the alkaline silicates. The silicates of potassa and soda lose by volatilization a large proportion of their bases. Thus, it may be explained how the multiple silicates containing alkaline silicates become less and less fusible as these are allowed to remain for a longer time in furnaces at a very high temperature, and acquire, with time, the property of crystallizing by slow cooling, at the same time losing their vitreous appearance.

We have seen that the alkaline silicates which contain a large proportion of alkali are soluble in water. When they contain more silex, they are not attacked by this fluid, but they may be by powerful acids; but when they are still richer in silex, even acids do not affect them. The silicates of lime, alumina, and oxide of lead are attacked by acids when they contain a large proportion of base, but they are intangible when rich in silex. Fluohydric acid, however, decomposes every silicate, whatever proportion of silicic acid it may contain, for it attacks quartz itself. By combining the alkaline silicates with silicate of lime, double silicates are obtained sufficiently fusible to be worked by blowing, and nevertheless containing enough silicic acid to resist the action of acids.

We shall divide the various kinds of glass into three grand classes;—

1st. Common colourless glass, which is a double silicate of lime and potassa or soda.

2nd. Common coloured glass, or bottle glass, a multiple silicate of lime, oxide of iron, alumina, and potassa or soda.

3rd. Crystal, which is a double silicate of potassa and oxide of lead.

1st. *Colourless Glass.*—Common colourless or white glass, which is used for making tumblers, window glass, and looking-glasses, is a double silicate of lime and potassa or soda, either of these being preferred according to its price. Carbonate of soda being much cheaper in France than carbonate of potassa, is almost exclusively employed in the manufacture of white glass; in Germany and the north of Europe the potassa, being cheaper, is preferred. The selection of these bases is not a matter of indifference. Soda yields a more fusible and easily-worked glass, but it is always more or less coloured by a greenish-yellow tinge, not perceptible when the glass is very thin, but very decided when it is thicker, as, for example, in a window-pane.

The most beautiful glass having a base of potassa and lime is the Bohemian. This glass, made with the utmost care from choice materials, is remarkable for its lightness, its brilliant transparency, and permanency. The ratio between the oxygen of the silicic acid and that of the bases is as 4 : 1, sometimes rising to 6 : 1; the oxygen of the lime is to that of the potassa as 1 : ¾ in the most esteemed tumbler-glass of Bohemia. This proportion is as 1 : 1 in the glass used for mirrors, in which great fusibility is required. The proportion of silex is increased in order to make hard and infusible glass; in this way the Bohemian glass tubes for chemical purposes are made, as they are much less fusible than the French glass, and therefore preferable for organic analysis. The silex used in Bohemia is the hyalin quartz of the old rocks, found in the form of large pebbles in the fields or the beds of the mountain streams. This quartz is heated to a strong red-heat in a reverberatory furnace, and then thrown into cold water, by which it becomes very friable, and is then, without difficulty, finely powdered by stampers, or ground by edge-stones. The carbonate of potassa used in the manufacture of Bohemian glass is the refined carbonate; nevertheless, this salt is never pure, some carbonate of soda always being mixed with it. The crude potashes are carefully selected and refined by solution: the crude potash, on being treated with one-half its weight of water, leaves the foreign salts, as well as a considerable quantity of carbonate of potassa, as a residue. The solution yields, when evaporated, potassa for the manufacture of first-quality glass, while the remainder serves for that of an inferior quality. The lime is obtained by subjecting a very pure and often perfectly white saccharoid carbonate of lime to calcination in a reverberatory furnace.

When these materials, however carefully they may have been selected, contain a small quantity of protoxide of iron, a greenish tinge, which greatly lessens its commercial value, is imparted to the glass. This discoloration is remarkably destroyed by adding to the mixture a small quantity of peroxide of manganese. The protoxide of iron imparts a deep green colour to glass, when present in any quantity; but, if converted into a sesquioxide, it gives a scarcely perceptible yellow tinge. Sesquioxide of manganese colours the glass violet; but a corresponding quantity of protoxide scarcely produces a sensible change. If, therefore, to a mixture to which protoxide of iron would give a high colour, a quantity of peroxide of manganese sufficient to transform the protoxide of iron into a sesquioxide, by passing itself into the state of a protoxide of manganese, is added, a nearly white glass is obtained; for the colour it then has is due only to the sesquioxide of iron, which produces a scarcely perceptible yellow tinge, the protoxide of manganese effecting no colouring at all. But it is important not to use an excess of peroxide of manganese, because the glass would have a violet shade, owing to the formation of sesquioxide of manganese. Peroxide of manganese, on account of this special use, is called the *glass-maker's soap*. Frequently, also, a small quantity of arsenious acid is added to the mixture: as this acid is completely volatilized during the melting of the glass, none of it remains in the objects manufactured: its object is merely to render the mixture more homogeneous, or to facilitate the *refining* of the glass. By volatilizing at a high temperature, it forms bubbles of gas, which, on traversing the fluid mass, mix its several particles together, and precipitate the solid material scattered through it.

The fuel used in Bohemia is a resinous wood, burning with a bright flame, and causing a very rapid fusion. The air of the furnace being always oxidizing, no alteration of the glass need be feared by the carbonaceous dust or other particles contained in the smoke. An admixture of carbon would considerably injure the quality of the glass, and discolour it; but when it exists in small quantity, the glass assumes a beautiful yellow colour. These coloured glasses are often made expressly. When it is present in somewhat greater quantity, the glass assumes a purple-red colour. Peroxide of manganese opposes also this discoloration of glass by carbon, an accident which frequently happens when the furnace has no proper draught. In some glass-houses, it is prevented by the addition of a small quantity of nitrate of potassa.

A white glass of first quality is made by melting together 110 parts of pulverized quartz, 64 parts of refined carbonate of potassa, and 24 parts of caustic lime.

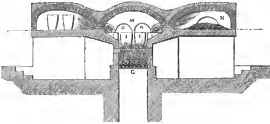
In other glass factories in Bohemia beautiful tumbler-glass is made of a mixture of 120 parts of pulverized quartz, 60 parts of refined carbonate of potassa, 25 parts of caustic lime, ½ part of arsenious acid, 2 parts of peroxide of manganese, and 2 parts of nitre.

First-quality white glass is made in France of white quartzose sand, artificial soda, quicklime, and a certain proportion of fragments of glass: in this glass the ratio of the oxygen of the silicic acid to that of the united bases is ordinarily as 4 : 1. This composition gives an easily fusible but slightly tender glass. When a harder glass is desired, the proportion of silicic acid is increased. A fine sand, as white as possible, is selected, and sometimes made more friable by heating it to redness, and throwing it in that state into cold water. The sands from Aumont, near Senlis, from Etampes and Fontainebleau, are highly esteemed, and are exclusively used in the glass factories in the environs of Paris. The lime is obtained from a limestone as pure as possible, and previously calcined in an oven to drive off the carbonic acid; it is then exposed to the air, and falls to dust. It is sometimes used in the state of carbonate of lime, finely powdered. Very white chalk, as that from Bougival, near Paris, is perfectly adapted to this purpose. For first-quality white glass, the carbonate of soda obtained in the manufacture of artificial soda is used. For the inferior qualities, sulphate of soda, which is cheaper than the carbonate, is substituted; but as the sulphate of soda is decomposed by silicic acid only at a very high temperature, at which the crucibles would soon be destroyed, a certain quantity of charcoal is added: this facilitates its decomposition, by abstracting a portion of the oxygen from the sulphuric acid, thus causing it to pass into the state of sulphurous acid, for which the affinity of soda is much more feeble. One part of charcoal is generally mixed with 12 or 14 of sulphate of soda.

The materials, intimately mixed, undergo a preliminary calcination called *frit*, before being placed in the melting pots, intended to commence the combination, and at the same time to allow the substance to be introduced into the melting pots already heated to redness. The breaking of the pots by sudden cooling is thus avoided, and the fusion is more rapid.

Figs. 3258, 3259, represent a glass furnace for the manufacture of window glass. Fig. 3259 gives a horizontal section made at the height of the line A B of Fig. 3258; Fig. 3258 represents a vertical section of the oven, in the direction of the line C D of Fig. 3259. The oven is composed of an arched space M, in the middle of which is the grate G above the ash-hole. On each side of the grate are two shelves F, of strong mason-work, on which the pots I I are placed; the pots are introduced through several doors in the upright wall of the oven, which are subsequently closed up with bricks. A circular opening *o* is preserved above each pot, large enough to allow the material to be withdrawn and to introduce into the oven the object to be manufactured. The flame of the fuel on the grate G rises in the oven M; it is then conducted by openings into the lateral ovens N N, called *arches*, in which the preliminary preparation is made, the *frit* of the mixture; in these same arches, the new pots are kept for a long while before introducing them into the principal oven, in order gradually to prepare them to bear the high temperature of the ovens, and render them stronger. The flame and smoke, having passed through the ovens N, escape by the flues. Each pot is attended by two workmen, a master glass-blower and an assistant. The master-blower, standing on a small wooden bridge L, raised from 1 to 1½ mètre above the ground, is thus enabled to dip into the pots and handle the pieces he is about to blow. Small walls *n n* separate the working spaces of each pot, in order that the blower may not be inconvenienced by the heat of the adjoining working hole.

3258.



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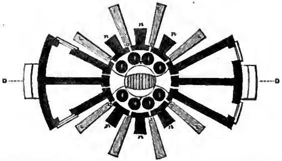

Great care is required in the manufacture of the melting pots; only the most infusible clays can be used; the process will be described under the head of POTTERY. They are generally $0^{m} \cdot 7$ to $0^{m} \cdot 9$ in depth, and will hold about 400 or 500 kilogrammes of melted material. The pots when newly made are kept for several months in hot rooms, so as to dry slowly. They are then introduced into the arches of an oven, the temperature of which is not very high, and are gradually and slowly brought nearer to those parts of the arch where the heat is greatest. They are introduced into the principal furnace only after having been subjected to a very high temperature. Each pot should serve for several meltings; it is rarely necessary to replace all the pots of a furnace by new ones. They are thrown aside as they wear out, and a sufficient supply should always be kept in the arches, to replace those which are destroyed.

The mixture of the material is generally composed of 100 parts of sand; 35 to 40 parts of chalk; 30 to 35 parts of carbonate of soda, or an equivalent quantity of a mixture of sulphate of soda and charcoal; and 50 to 150 parts of broken glass, or *cullet*. These materials, intimately mixed, are set to frit in an arch of the furnace, where they are turned from time to time, in order to render the mixture more uniform. The fire on the grate is made to burn actively after the working holes of the furnace have been closed. The workman deposits the frit in the pots, removing it red hot from the arch with a shovel; after the addition of each shovelful he waits until the material is melted before adding another, and so on until the pot is filled. He then leaves it to itself for several hours, in order to clear it of bubbles of air and foreign substances which rise to the surface. These substances, called *glassgall* (also called *sandiver* or, commonly, *salts*), are formed by alkaline salts in excess, which have not been decomposed by the silicic acid; they are particularly numerous when impure carbonate of soda has been used, or when a mixture of sulphate of soda and charcoal has been substituted for it. The workman generally removes them with an iron ladle. From time to time he extracts a small quantity of melted glass, and judges of its quality by its appearance after solidification.

When the glass is sufficiently fused, the temperature of the furnace is lowered, in order to bring the glass to a consistency fit for working. We shall not attempt to describe the processes of glass blowing in detail, but merely that adopted in France for the making of window glass.

The *pipe*, Fig. 3260, is the principal tool of the master-blower. It is an iron tube, $1^{m}\cdot50$ in length, having a perforation through its long axis of 3 millimètres in diameter; it is covered externally, to a distance of about 35 centimètres, by a wooden tube *c d*, to protect the workman's hand from the intense heat. At the end of each bridge L, Fig. 3259, is a small platform, of the height of $0^{m}\cdot65$, protected by an iron plate, called the *marver*, on which the workman moulds the doughy glass, Fig. 3261, adhering to the end of the pipe into the proper shape for blowing. Near the *marver* is a wooden block, containing several hemispherical or pear-shaped cavities, which are kept constantly moist. The pipes are heated in a small opening at the base of the furnace. The workman, taking one, dips it into the glass, collects a certain quantity, withdraws it, and turns it so that the fluid glass may not separate, then collects an additional quantity, and hands the pipe thus charged to the master-blower. The latter, having received it, rests it on the iron platform, always turning it, dips it again into the pot, and then returns quickly to the platform with a mass of red-hot glass, and rests it, still keeping up the rotary motion, in the water which fills the cavity of the block. He then draws the greater portion of the glass which envelops the sides toward the end of the pipe, by means of a sheet-iron blade, Fig. 3262. The mass of glass, cooled by the water, but adhering to the end of the pipe, is carried back to the working hole to be softened. When the workman thinks it is soft enough, he withdraws the pipe, and recommences the same manipulation in the water, but at the same time blows in the pipe, so as to give the glass the shape of a sphere of about 3 decimètres in diameter, Fig. 3263, and then suddenly lifts the pipe into the air, and blows the sphere above his head. The upper part of the sphere then sinks by its own weight, and the bulb spreads horizontally, Fig. 3264. By suddenly dipping the pipe, the sphere assumes the shape of Fig. 3265. The workman then swings the pipe backward and forward, like the pendulum of a clock, blowing from time to time through the pipe while making this movement, so that, by the simultaneous action of weight and blowing, the glass balloon elongates and assumes the shape of a cylinder, Fig. 3266. The glass cylinder can rarely be brought to the proper dimensions by one operation, but generally must be heated several times in the oven. When the cylinder is finished the master-blower rests the pipe on a portable hook which the assistant arranges in the direction of the working hole; and introducing the cylinder into the furnace so that its end becomes excessively heated, blows through the pipe with the whole force of his lungs, until the cylinder is pierced. The piercing of the cylinder is also often effected in another manner. The assistant fastens, by means of a pipe, a small quantity of very hot glass to the extremity *o* of the cylinder; this end the workman dips into the oven, and blows forcibly through the pipe, or simply stops its orifice with his finger. The pressure of the internal air bursts the end *o*, where the glass has been softened by the drop of hot glass, Fig. 3267. The workman then removes the cylinder from the

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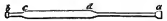

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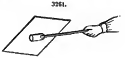

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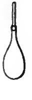

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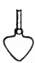

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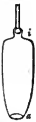

fire, and the assistant cuts off with scissors the convexity of the cylinder, so as to open it entirely, Fig. 3268; the blower then moves the pipe with great rapidity, either by swinging it or causing it to revolve completely. This manœuvre cools the glass rapidly, at the same time preventing the object being made from becoming mis-shaped. When the glass is solid, the blower gives the pipe to the assistant, who, resting it on a trestle, at the same time applies a drop of water, taken up with a bent iron rod, to the point of junction of the pipe and cylinder, and, by a slight blow on the middle of the pipe, detaches the cylinder. The cylinders thus prepared are intended for window glass; but, being as yet opened at one end and closed at the other, this end must also be opened. As the panes must have a given size, the workman applies to the upper edge of the cylinder a stick on which the size of the pane is marked; then, without moving the stick, he dips from the pot, with an iron rod, a drop of glass, which is elongated by drawing out; by applying this red-hot glass thread to the circumference *c b* of the cylinder, Fig. 3269, at the line to be separated, a very accurate division is immediately effected.

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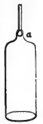

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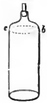

The glass cylinders are then carried to the *flattening* furnace, Figs. 3270, 3271, which is composed of two adjacent ovens V, U, separated only by a very small thin brick wall, extending from the floor to the roof. Beneath this partition wall is an opening *i i*, of 1 mètre in breadth, and a few centimètres only in height, serving for the passage of the panes, which having been flattened in the first compartment V, are reheated and slowly cooled in the chamber U. Both compartments are heated by furnaces beneath. The cylinders to be flattened are laid on a table; a drop of water is passed over the upper edge *c d*, Fig. 3272, followed by a red-hot iron, which effects a clean fracture throughout the whole length; after this the cylinders are presented to the opening O, Fig. 3271, of the flattening furnace, being gradually introduced into it by means of two grooves, which regulate their progress, thus avoiding a too sudden heating, which might crack them. When the workman sees that the cylinders are about bending on themselves, he takes the hottest on the end of an iron rule, and draws it into the middle of the furnace, near the flatting plate V, Fig. 3271, which is often made of cast iron, and sometimes of thick plate glass, dusted with a little plaster to prevent adhesion. This plate is placed immediately in front of the longitudinal opening *i i*, through which the pane must pass to enter the baking furnace U; its upper surface should also be exactly on a level with the floor of the furnace, so that the pane of glass may meet with no impediment in its progress. The cylinder having reached the plate, the workman, armed with his rule, presses down to the right and left the two sides, which yield readily to the weight of the rule, Fig. 3273. He then takes another iron bar, Fig. 3274, terminating in a highly-polished piece, and applying this polished part on the glass, passes it rapidly over the surface, so as to flatten it perfectly.

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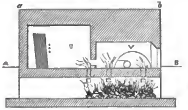

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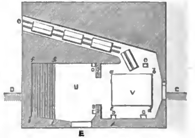

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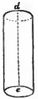

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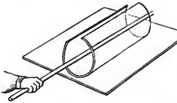

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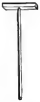

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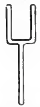

The pane, properly flattened, is pushed through the longitudinal opening *i i* into the second compartment U, where the temperature is much lower; a workman passes beneath it a thin iron rule, terminating in a fork, Fig. 3275, and raising the pane, which is already firm enough not to bend, rests it in a vertical position against an iron bar *f f*, Fig. 3271, which passes through the whole length of the oven. A number of panes are thus heaped on each other, until the workman deems it sufficient. A second horizontal bar is then arranged, on which additional panes are disposed, and so on until the compartment U is nearly filled. The furnace is then allowed to cool; and the glass, when withdrawn, is ready for sale. Clock-shades, decanters, tumblers, &c., are made of the same glass. Inferior glass articles, such as common window glass, apothecaries' phials, &c., are made of less pure materials; they are commonly coloured green by protoxide of iron.

In France, the base of plate glass is a mixture of soda and lime, and the oxygen of the silicic acid is to that of the united bases as 6 : 1. For the same quantity of lime, a quantity of carbonate of soda is added double of that contained in window glass, because it is necessary to give greater fusibility to plate glass. In the plate-glass factory of Saint-Gobain, which is the largest in France, the mixture is made of 300 parts of very white quartzose sand, 100 parts of dried carbonate of soda, 43 parts of lime slaked in the air (fallen lime), and 300 parts of cullet. The materials are most carefully selected and purified; for it is essential to obtain as white and perfect a glass as possible. Melting furnaces similar to those described are used, but they are always heated by wood. The material passes successively into two pots; it is first melted in a conical one, into which it is gradually poured until the pot is nearly filled. This fusion requires fifteen to sixteen hours; it is then allowed to fine, by rest, at a high temperature. Workmen then remove the liquid glass with copper ladles, and transfer it to smaller square pots, called *cuvettes*, placed in the furnace on the same shelf and alongside of the melting pots. When the transfer has been effected, the working holes are closed, to restore fluidity to the glass; the cuvettes are then removed on a peculiar kind of cart, and brought above a very smooth bronze table, previously heated by red-hot coals laid thereon. The fluid glass is poured on this table, spread out, and smoothed by means of a cylinder or roller; when cooled it is placed in a furnace and again heated, in order that it may easily bear changes of temperature. It is then divided into pieces of the requisite size, leaving out the defective portions, and *polished*, by fixing the glass on a stone table with plaster, and rubbing it with quartzose sand, by means of a second piece of glass smaller than the first. In making large glasses, several pieces, set in motion by a machine, are used at once. The surface of the glass thus becomes perfectly smooth, and is *rough-ground*, but as yet unpolished. The final *polish* is given by rubbing the surface first with finer emery, diluted with water, and then rubbing it with colcothar, also diluted with water, by means of heavy polishers covered with felt.

2. *Bottle Glass.*—Bottles are made of cheap materials, because it is important that their price should be low, and the peculiar colour is not a matter of much importance. The most ochreous sands are frequently preferred, because the oxide of iron they contain imparts fusibility to the glass. Pure alkaline carbonates being too expensive, the alkaline material is furnished by the crude sea-soda and wood ashes. A considerable portion of washed ashes, called *spent ashes*, is added, which introduces the silicates of alumina and potassa. Lastly, a large quantity of cullet is poured into the mixture. In bottle glass, the oxygen of the silicic acid is double or treble that of the united bases. The following is the composition of a mixture used for bottle glass;—

Ochreous sand	100	Spent ashes	150 to 180
Soda from seaweed ..	40 to 60	Ochreous clay	80 „ 100
Fresh ashes	30 „ 40	Cullet	100 „ 150

Bottle glass is of various colours. That of French bottles is a deep green, owing to protoxide of iron; those made in certain parts of Germany have a brownish-yellow hue, produced by a mixture of the sesquioxides of iron and manganese. Bottle-glass furnaces generally contain six pots of the largest size. The fusion should be rapid, to economize the fuel. The pots being entirely filled with the mixture, the fire is stirred up to effect the fusion, and when the material is liquid, a fresh quantity is added; seven or eight hours are required thus to fill the pots with melted glass, after which the work is begun immediately, the sandiver first being removed. The furnace is allowed to cool until the material has acquired the degree of consistency proper for working.

The pipes having been heated in the holes at the bottom of the furnace, an assistant dips one into the melted glass, collecting as much of it as he can, and withdraws it by a continuous rotary motion. When the glass has become sufficiently consistent not to bend on itself, he collects some more, and so on; when he has gathered enough to finish a bottle, he passes it to the blower, who applies the glass to the left face of the marver, turning the pipe constantly, in order to fashion the neck of the bottle; at the same time he compresses the glass at the end of the pipe by means of the sheet-iron plate, Fig. 3262, and then blows through the pipe, so as to give the glass an egg-like form, Fig. 3276. He then rests the glass against the edge of the marver, marks the neck of the bottle, heats the piece in the furnace, withdraws it, and blows it, after having introduced it into a bronze or earthen mould of the proper size. When the bottle is formed, the blower withdraws it from the mould, and by a see-saw motion raises it on high, Fig. 3277, and indents the bottom of the bottle, by mean of an instrument, Fig. 3278, called the *punty* or *pontil*, consisting of a small square piece of sheet iron, the angle of which rests on the centre of the bottom of the bottle, while it revolves on the pipe. Then, taking a drop of water with the punty, he applies it to the neck of the bottle, which is immediately carried to a small cavity in the side of the furnace, and separated from the pipe by a dexterous jerk. The bottle being thus prepared, the blower turns it, and fastening the pipe to its base, Fig. 3279, extracts from the pot with another pipe a small quantity

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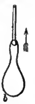

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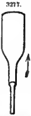

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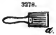

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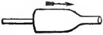

of melted glass, which elongates like a thread; the end of this he brings to the neck of the bottle, and by a rotary motion surrounds the mouth with a small glass cord; he then introduces the neck into the working hole, and finishes the mouth with pincers. The bottle being completed, an assistant takes it from the hands of the master-workman, carries it to the annealing furnace, and detaches the pipe by a dexterous blow. The bottles are arranged in rows, upon each other, in the annealing furnace, the heat of which should be kept below a dull red. When it is filled, the working holes are closed, and it is allowed to cool. Modern annealing furnaces are composed of a long gallery, heated by a furnace in the centre, and terminating by doors at either end. This longitudinal furnace is traversed by an endless iron chain, to which iron carts are attached containing the objects to be annealed. They enter at one end, and are withdrawn at the other, after having remained in the furnace long enough to be properly annealed.

3. *Crystal* is a kind of glass used only for the fabrication of articles of luxury; it must therefore be very transparent, perfectly homogeneous and colourless, and the greatest care must be exercised in the selection of the materials for its composition. Crystal is a double silicate of potassa and oxide of lead, the composition varying greatly in the different factories; the proportion of the oxygen of the silicic acid to that of the united bases ranges from 6 : 1 to 9 : 1. The ratio of the oxygen of the potassa to that of the oxide of lead ranges between still wider limits, namely, from 1 : 1 to 1 : 2·5. By increasing the proportion of oxide of lead, greater density and higher refracting and dispersing powers are imparted to the crystal, which produce in cut glass the beautiful effects of colour by transmitted light. But the proportion of the oxide of lead cannot be increased indefinitely, because the crystal, in that case, acquires a yellowish tinge. The finest and purest sand is chosen for the manufacture of crystal; the carbonate of potassa employed is refined, and the ordinary oxide of lead or *litharge* is not used, because it always contains some particles of metallic lead, which would be scattered through and injure the glass. Minium, an oxide of lead of a degree of oxidation superior to the protoxide, only is used: this oxide cannot contain metallic lead, and the oxygen it evolves when heated prevents the reduction of any lead by the carbonaceous dust or particles of other substances which may fall into the pot. The ordinary proportions for tumblers, decanters, &c., are 300 parts of pure sand, 200 parts of minium, and 100 parts of purified carbonate of potassa.

Crystal-glass furnaces are generally heated with wood; in some, however, coal is burned, but in that case the shape of the pots must be changed. Coal produces a very fuliginous smoke, the deoxidizing action of which it would be very difficult to prevent, if the glass were melted in open pots; peculiarly shaped pots, Fig. 3280, called *covered crucibles*, or *muffles*, are therefore used; their vertical opening is placed in front of the working hole of the furnace.

Many articles are made of crystal by blowing, but it is also cast in great quantities in bronze or wooden moulds, which latter are kept moist, so as not to carbonize too rapidly.

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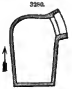

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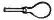

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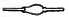

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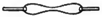

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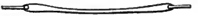

The glass tubes used by chemists, and also thermometer tubes are made by a particular process, which we shall briefly describe. The workman gathers on the end of his pipe a certain quantity of glass prepared as usual; he then blows it into the shape of a pear, Fig. 3281, which he makes larger or smaller, thicker or thinner, according to the size and thickness of the tube required. Another workman has also gathered some melted glass on the end of a pipe, and applies it to the bottom of the bottle, Fig. 3283; the two workmen then recede rapidly from each other. The glass pear is then drawn out, as seen in Figs. 3283, 3284, and is converted into a tube terminating into two swollen extremities. Tubes of 30 or 45 mètres in length are thus made; they are laid on a wooden floor, and divided into lengths of 1 mètre each. It will be seen that the external diameter of these tubes is not equal throughout its whole length, being generally smallest toward the centre; neither is the internal calibre more regular, and it is rare to find a tube possessing the same internal diameter throughout its whole length.

Manufacture of Glass for Optical Purposes.—Crown Glass and Flint Glass.—Two kinds of glass are used for optical instruments; one, called *crown glass*, is analogous in its composition to Bohemian glass, while the other, called *flint glass*, is a species of crystal. This glass must be as colourless as possible, and perfectly homogeneous; great care is therefore required in the choice of the materials entering into its composition, and they must be refined expressly. Ordinary flint glass is manufactured of 100 parts of white sand, 100 parts of minium, and 30 parts of very pure carbonate of potassa. The density of this flint is about 3·5. A more refracting flint, but one slightly coloured yellow, is made of 225 parts of white sand, 225 parts of minium, 52 parts of carbonate of potassa, 4 parts of borax, 3 parts of nitre, 1 part of peroxide of manganese, 1 part of arsenious acid, and 89 parts of cullet of the preceding flint.

The melting furnace, Fig. 3285, contains only one covered crucible or pot, into which the mixture is gradually introduced by small portions at a time, always waiting until the preceding charge has become perfectly fluid. Eight or ten hours are required for the whole charge of a pot. A strong blast is then applied, and kept up for four hours, to render the mixture perfectly fluid. When this is effected, a hollow cylinder *a b*, made of fire-clay, previously heated to redness, and which does not sink in the melted glass, on account of its greater lightness, is introduced into the pot. Into the cavity of this cylinder a curved iron bar *f e* is passed, the end of which is heated to redness. By resting this bar on an iron gallows *k l*, the clay cylinder may be moved in any direction, so as to mix intimately the various parts of the liquid mass. The bubbles of air are thus driven out, and the whole rendered perfectly homogeneous. This operation must be frequently repeated, to make the glass as perfect as possible. The clay cylinder is then removed, and the furnace allowed to cool slowly for eight days. The pot is then taken out, and is broken after cooling, to retract the glass, on which small polished facets are cut, here and there, so as to judge of its quality in various parts. This mass is then broken into pieces, and those that are perfect are selected, and heated in a muffle to soften them; they are then rolled into balls with pincers, and afterward carried to moulds which give them a lenticular shape. Lastly, they are allowed to cool slowly in an annealing furnace.

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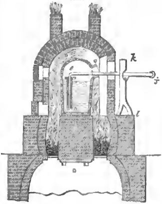

Crown glass is made exactly in the same way, of 120 parts of white sand, 35 parts of carbonate of potassa, 20 parts of carbonate of soda, 20 parts of chalk, and 1 part of arsenious acid.

By joining two lenses, properly cut, one of crown and the other of flint glass, *achromatic lenses* are obtained, which are remarkable for their property of giving the same convergence to all the coloured rays, so that a colourless object produces, in the focus of the compound lens, an image equally colourless, the edges of which are free from the coloured fringes always presented by images seen through simple lenses. This property, however, is very manifest only in those rays which do not depart very far from the axis of the lens.

Strass.—A peculiar kind of crystal is sometimes made, very dense and refracting, resembling the diamond when it has been properly cut. By colouring this glass with various metallic oxides coloured glasses closely imitating the precious stones are obtained. This crystal, called *strass*, should be made of the purest materials, and requires great care in fining: generally, a certain quantity of borax is added. The manufacture of artificial jewels has in modern times reached great excellence.

Enamel.—The name of *enamel* is given to a species of glass rendered opaque by an addition of certain metallic oxides. Peroxide of tin or stannic acid is generally used for this purpose: however, arsenious acid, phosphate of lime, or antimoniate of oxide of antimony may also be employed. Enamel is generally made of a very fusible crystal. An alloy of 15 parts of tin and 100 parts of lead are oxidized in a reverberatory furnace, by which a stannate of oxide of lead is formed, which is purified by levigation. 100 parts of this plumbeous stannate are then mixed with 100 parts of very pure sand and 80 parts of carbonate of potassa. An addition of small quantities of certain metallic oxides to this mixture gives coloured enamels.

Of the Imperfections and Alterations to which Glass is subject.—We have seen that objects made of glass are kept for some time in a furnace at a dull red heat, and then allowed to cool slowly. This process, called *annealing*, is a very essential operation, for glass cooled suddenly after blowing is so brittle as to be useless. It frequently happens that common tumblers, which are imperfectly annealed, break suddenly on a slight change of temperature; such glass sometimes, also, is fractured when exposed to the current of air from an open door. This property is highly developed in the *lachrymæ Batavicæ*, or *Prince Rupert's drops*. These are drops of glass suddenly cooled, and made by allowing drops of melted glass to fall into cold water; they thus become suddenly solid, in the form of tears, Fig. 3286, terminating in a long tail; and as the outer surface solidifies while the interior is still at a high temperature, it retains nearly the shape it had in the liquid state. The internal particles are kept in an abnormal condition by those of the surface surrounding them. If this resistance of the surface particles be removed, at only one point, the whole mass bursts with noise, and falls into dust. This occurs, for example, if the tail of the drop be broken off. A similar effect is produced in a small glass apparatus, long known as the *philosopher's phial*, a kind of glass tube, thick, and of a pyriform shape. The master-blower frequently makes them on his pipe, when trying the metal in the pot. If any hard substance, a small ball, for example, be dropped into this phial, which has not been annealed, the shock is sufficient to reduce the phial to dust. The workmen apply this tendency of glass to break in a given direction when touched with a cold body, to detach the pipe from the objects blown, or to crack the glass in any direction required.

3286.

When glass has been exposed for a long time to a high temperature, it loses, by volatilization, a considerable portion of its alkali, and becomes less and less fusible, at the same time acquiring the property of readily crystallizing by slow cooling. Thus masses of glass of a crystalline structure are often found in the worn-out pots which have been for a long time in the furnace, and cooled slowly; at other times, the crystallization is developed only in some parts of it, the remainder being vitreous; the vitreous portion always containing more alkali than that rendered opaque by crystallization. This alteration of the glass takes place not only at its fusing point, but also at a lower temperature. If a glass bottle be left for several days in a furnace, at a degree of heat approaching that which effects the softening of the glass, it entirely loses its transparency, and resembles a porcelain bottle. The glass thus altered, *devitrified*, is much less fusible than when transparent. A peculiar art was attempted to be founded on this property, which consisted in making objects of blown glass, and then destroying their fusibility by devitrification. This devitrified glass was called *Réaumur's porcelain;* but the manufacture of it has been abandoned.

Glass containing a large proportion of alkali changes by exposure to moist air, its surface becoming rugose and cracked. Frequently an excessively thin pellicle of altered glass forms on it, producing the same play of colours as a soap-bubble, or a drop of oil on a large surface of water; an alteration produced by the surface of the glass parting, after a long time, with a portion of its alkali. It is particularly remarkable in pieces of glass which have remained buried for years in a damp soil. These pieces are sometimes found to have entirely lost their transparency, to be swollen, and cleavable into very thin lamellæ: then they exhibit the same play of colours as mother-of-pearl.

Various small objects are made of the glass tubes of commerce. For this purpose an oil lamp, generally made of tin, Fig. 3287, fed by a bellows, and called an *enameller's lamp*, is used. The wick is of cotton, and does not project very high. The bellows is worked with the foot: the blast of air is conveyed by a pipe which can be turned in various directions. By properly arranging the wick, and modifying the inclination of the pipe, and adapting a proper aperture to it, a flame of any size may be obtained at pleasure. When working with a plumbeous glass, or crystal, the flame must be made oxidizing by admitting a greater quantity of air; for if the flame were reducing, oxide of lead would be brought to the surface of the glass in the state of metallic lead, and the glass would be blackened. It is important not to heat the glass too suddenly, lest it should break; it is therefore first held for a few moments before the flame, and brought by degrees into the hottest part.

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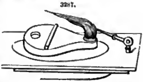

In order to bend a glass tube, it is heated to the distance of 3 or 4 centimètres on each side of the point of flexion, turning it constantly, so that its whole periphery may be uniformly heated. As soon as the tube is sufficiently soft to yield to a slight force, it is bent; but it is important not to make the curve too short, because the tube would be mis-shaped and brittle. The tube is therefore not heated at the point where it was begun to be bent, but the flame is directed on the adjacent part, so as to make a small arc of a circle. Tubes can be bent in an alcohol lamp even more readily than in an enameller's lamp, for it is better not to have the glass too hot.

In order to close a tube at one end, a longer tube is heated in the enameller's lamp, at the point of closure, turning it constantly in the flame. As soon as it is perfectly soft, both ends are gently drawn out, still turning it. The tube thus takes the shape of Fig. 3288. The point of the flame is then directed to the point *a* of the narrow part, and the two halves of the tube are separated, each of which will furnish a tube closed at one end; the ends are then rounded, and made more uniform in thickness. To do this, the end is again heated in the lamp, blowing into it occasionally, to round it. Lastly, a *border* is only required to complete it, which is made by simply heating the sharp edges until they are rounded by fusion. If the edges are to be widened, or a mouth made to pour liquids, it is done by applying an iron wire against the softened edges, by which means the aperture can be fashioned at will, Fig. 3289. When the end is to be closed, this end is heated in the lamp, and the heated end of another tube applied to it. The two tubes are soldered together, and the operation is then continued as just described.

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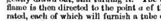

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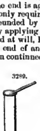

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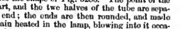

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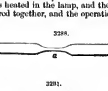

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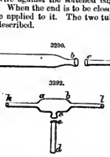

It is frequently necessary to solder a smaller tube *c d*, Fig. 3290, to the end of a larger one *a b*. The larger tube is then drawn out, in the lamp, till it is of the size of the smaller one, and the tube *a b* is next closed at the point *b* of the narrow part, by placing the part *b* in the point of the flame, and turning the tube between the fingers. Then, after having heated the closed end to soften it, a very thin sphere, which bursts by blowing through the opening *a*, is formed at the end *b*. By means of a file the glass is separated so as to leave only a widened edge-border at the end *b*. The same is done to the end *c* of the small tube; the ends *b* and *c* are then exposed to the flame, opposite to each other, turning them constantly, after having previously closed the end *a* with a cork. When these ends are sufficiently softened, they are pressed firmly against each other, the joint is equally heated throughout, and from time to time the operator blows through the small tube, in order to prevent the solder from forming a ring. Lastly, it is drawn out slightly, so that no swelling may exist at the point of union.

If a narrow tube *c d*, Fig. 3292, is to be soldered to the side of a larger tube *a b*, the point of the flame, after having rendered it as sharp as possible by a proper arrangement of the pipe and lamp-wick, is directed on the point *c*, Fig. 3291, of the tube *a b*. When it is sufficiently softened, the end of a glass point, also heated, is fastened and drawn quickly forward: thus a point $e\,f$ is formed on the tube $a\,b$. This point is closed in the lamp; then, having stopped the end k with wax, the point $e\,f$ is again introduced into the flame, and when it is in fusion, a very thin sphere, which bursts, is formed by blowing through the open end l. A portion of the glass is filed off, the edges of the aperture are melted, Fig. 3292, and after having closed the end l with wax, the end e of the small tube, also heated, is brought in contact with the opening c. The joint is formed by gradually heating all its parts, and blowing from time to time through the opening d.

If a globe is to be blown at the end of a tube, the tube is closed in the lamp, and by continuing the action of the flame, a mass of glass, large enough to make the globe required, is collected at this end. This mass of glass being very soft, the tube is gradually extended by blowing gently into it. It is then heated again uniformly, and afterward, by constantly turning the tube and blowing gently, a globe of any size may be produced at pleasure. When the globe is to be large, and still be at the end of a narrow and thin tube, it is better to blow the globe separately on a larger tube, and then solder it to the narrow one. To do this, the larger tube is drawn out between two points, Fig. 3293, by the process before stated; one end, a, is closed in the lamp, and then the part A heated in the flame, so as to soften it completely. Lastly, the operator blows through the end b, turning it constantly, until the globe has attained the size required. The globe is then soldered to the tube. But as the globe is still terminated by a point, the latter is placed in the flame, and by blowing gently after having softened this part of the globe, it is distended so as to cause the small piece of glass to disappear. The bottles which are to contain the volatile liquids intended for analysis are blown in the same way.

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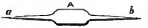

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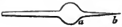

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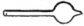

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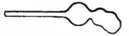

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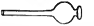

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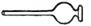


In order to fashion a funnel at the end of a tube, as, for example, on safety-tubes, a globe drawn out between two points, Fig. 3294, is soldered to the end of the tube, and then the point $a\,b$ is detached, Fig. 3295. The part a, as well as the end of the globe, is heated, and when they are very soft, a smart blow of wind through the tube is given; thus a second irregular and very thin globe, Fig. 3296, fastened to the first, is produced; this is broken and the glass detached by means of a file, Fig. 3297, so as to leave only an edge, which is melted in the lamp, and properly widened by an iron rod, Fig. 3298.

In order to break a glass tube at any given point, a mark is made on it with a gun-flint or a very sharp three-edged file; the tube is then pulled in the direction of its length, and it separates at the mark. If the tube be large, it must be slightly bent at the same time. In order to separate thicker and larger portions, as, for example, to shorten the neck of a retort or flask, a mark with a file is made at the proper point, and followed with a point of red-hot iron; it then cracks in the direction of the mark.

A red-hot coal, held with a forceps, carried round the intended line of separation, answers the same purpose; care must be taken to blow away the ashes as soon as they form by contact with the cold glass, so as always to present a red-hot point to the surface of the glass.

The process of dividing a tube by friction, described in Hare's Chemistry, is so much superior to that adopted by previous operators, that the Editor has not hesitated to substitute it for the French mode:—"Some years ago, Isaiah Lukens showed us that a small phial or tube might be separated into two parts, if subjected to cold water, after having been heated by the friction of a cord made to circulate about it, by two persons alternately pulling in opposite directions. We were subsequently enabled to employ this process for dividing large vessels of 4 or 5 in. in diameter; and likewise to render it in every case more easy and certain, by means of a piece of plank forked like a boot-jack, and also having a kerf or slit cut by a saw, parallel to and nearly equidistant from the principal surface of the plank, and at right angles to the incision forming the fork. By means of the fork, the glass is held steady by the hand of the operator. By means of the kerf, the string, while circulating about the glass, is confined to the part where the separation is desired. As soon as the cord smokes, the glass is plunged into water, or if too large to be easily immersed, the water must be thrown upon it. This method is always preferable when the glass vessel is so open that, on being immersed, the water can reach the inner surface. As plunging is the most effectual method of employing the water, we usually, in the case of a tube, close the end which is to be sunk in the water, so as to restrict the refrigeration to the outside."—Hare's Compendium, ed. 4th, p. 60.

Coloured Glass and Painting on Glass.—Glass dissolves the greater part of the metallic oxides, and while it preserves its transparency, is often tinged with the most beautiful hues; on this property the manufacture of coloured glass is founded. It suffices to mix intimately with the metal of which the glass is to be made, a given quantity of the metallic oxide, to produce coloured melted glass; with certain metallic oxides, however, peculiar care is required. Protoxide of iron FeO imparts to glass a deep or bottle-green colour, while the sesquioxide Fe_2O_3 produces a yellow tinge. Oxide of copper CuO and oxide of chrome Cr_2O_3 yield a beautiful green, but of different shades. Oxide of cobalt CoO gives a brilliant blue; sesquioxide of manganese Mn_2O_3 a violet. A mixture of equal parts of oxide of cobalt and oxide of iron colours the glass black. Protoxide of copper Cu_2O

yields a very beautiful red colour, but so intense that the glass nearly loses its transparency if the oxide be in the proportion of a few hundredths. A fine purple is obtained by mixing a certain quantity of oxide of tin with finely-powdered crystal, soaking the mass in a solution of chloride of gold, and melting it, when dried, in a crucible. When the metallic oxide to be used as a colouring agent can be deoxidized in the furnace, as, for example, the sesquioxide of manganese can be, a small quantity of nitre is added to the mixture. A beautiful yellow glass is made by adding lampblack to a mixture which would produce common white glass. By varying the proportion of lampblack, several intermediate shades between a bright and a purple yellow can be produced.

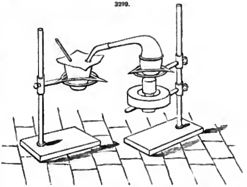
When it is wished to make glass of clear colours with metallic oxides which possess powerful colouring action, it is difficult to obtain the shade desired by adding the proper quantity of the colouring oxide to the mixture in the pot. Glass is then set in layers (*verre plaqué*), so that it is formed of white glass throughout the greater part of its thickness, and has one face only formed by a thin layer of coloured glass; and in order to vary at will the intensity of the colour, the layers are made of suitable thickness. This kind of glass is made as follows:—Two pots are placed in the oven, one filled with white and the other with coloured glass. The workman first takes up with his pipe a certain quantity of white glass; then, when it begins to assume the proper degree of consistency, he dips it into the coloured glass, and thus fastens a layer of this on the white mass. He then blows the whole into cylinders, in order to make muffs for flatting. The inside of the cylinder is necessarily white, the layer of coloured glass being only external.

Painting on glass is done with very fusible and finely-powdered coloured glass. The composition of this glass varies with the nature of the colouring oxide; for the majority of them, a mixture of 2 parts of quartz, 2½ of oxide of lead, and 1 of bismuth is used; but as certain colouring oxides are altered by the oxides of lead and bismuth, in this case a mixture of 2 parts of quartz, 1½ of melted borax, ½ of nitre, and ½ of carbonate of lime is used. The colouring oxide is added to these mixtures, and they are melted in a muffle furnace; the glass obtained is reduced to an impalpable powder, ground in turpentine, and the paint thus prepared is applied with a pencil. The painted glass is then heated in a muffle, at a temperature sufficient to melt the coloured glass, but not to affect the object on which the painting has been made. In order to form the groundwork of the picture, glass coloured in the paste is generally used, the outlines and shades being painted on one of the surfaces. The various pieces of glass are then dexterously fitted together by means of small sheets of lead, each small pane harmonizing with the outline and shades of the figure designed. The painted surface of the glass is placed outside, so that the picture is seen through the coloured glass. The numbers and divisions marked on enamel dial-plates are applied in the same way.

Analysis of Glass.—We will suppose that the glass to be analyzed contains, or may contain, silex, potassa, soda, lime, manganese, alumina, oxide of iron, oxide of manganese, and oxide of lead. Five grammes of the glass, reduced to an impalpable powder, are intimately mixed with about three times its weight of pure carbonate of soda; the mixture having been weighed in a platinum crucible, the latter is covered with its lid, and heated in an alcohol lamp having a double current of air, so as to completely melt the carbonate of soda. For this purpose, it is well to surround the crucible with a small sheet-iron chimney extending a few centimètres beyond it: the chimney, at the same time increasing the draught, forces the flame completely to envelop the crucible. The carbonate of soda is kept melted for at least twenty minutes, and then allowed to cool. By using a thin crucible, the alkaline cup may be detached by the pressure of the fingers, and is received in a porcelain saucer, containing a certain quantity of water, and covered by an inverted funnel. Water, acidulated with nitric acid, being poured into the platinum crucible, and then into the saucer, the alkaline cup dissolves with effervescence, the funnel preventing any loss of substance, by the projection of the small liquid pellicles surrounding the gaseous bubbles which burst on the surface of the fluid. Toward the close the liquid is acidulated with an excess of nitric acid, and evaporated to dryness at a moderate heat. Hot water, acidulated with nitric acid, is poured on the dried matter; it is allowed to digest for some time hot, and then diluted with water; all the metallic oxides then dissolving, leave the silex alone as an insoluble residue. It is collected on a filter, calcined after being well washed, and weighed. A current of sulphuretted hydrogen is passed through the liquid, which precipitates only the lead in the state of a sulphuret; and finally, the liquid is heated to ebullition, still keeping up the current of sulphuretted hydrogen, in order to facilitate the deposit of sulphur. The sulphuret of lead is collected on a filter, and, after having washed it, the filter is burned in a platinum crucible, and the substance sprinkled with nitric acid, mixed with a small quantity of sulphuric, in order to convert it into sulphate of lead; lastly, it is calcined to redness. The weight of the oxide of lead is deduced by calculation from the weight of the sulphate of lead obtained. Sulphydrate of ammonia is then poured into the liquid to precipitate the alumina and the sulphurets of iron and manganese; the wet precipitate is redissolved in chlorohydric acid, and by the separation of the two oxides. The liquid, which then contains only lime, magnesia, and the alkaline salts, is boiled to drive off the excess of sulphydrate of ammonia, and chlorohydric acid added to decompose that which still remains. Lastly, it is supersaturated with ammonia, and the lime precipitated in the state of oxalate of lime by oxalate of ammonia; the presence of ammoniacal salts in the liquid keeping all the magnesia in solution. The solution is then concentrated by evaporation, an excess of carbonate of soda added, and it is evaporated to dryness, to decompose the ammoniacal salts, and drive off the ammonia as carbonate; it is then treated with water, which leaves the magnesia in the state of insoluble carbonate.

In the analysis just described, the proportions of all the various components of the glass have been ascertained successively, with the exception of those of the alkalies, which must be found by a particular process. The glass is first dissolved in fluohydric acid. As this acid is difficult of preservation, it is better to prepare it freshly for each analysis, which is done in the following manner:—Into a small platinum retort, Fig. 3299, made of two pieces, very finely powdered fluor-spar is introduced and sulphuric acid added; on the other hand, 5 grammes of glass in impalpable powder are placed in a large platinum crucible, with a certain quantity of water, and covered with a sheet

3299.



of platinum pierced with two openings. The neck of the platinum retort passes through one of those openings; the other, much smaller, is traversed by a platinum wire, flattened into a spoon at its end, and used for stirring the material in the crucible. On gently heating the retort the fluohydric acid dissolves in the water of the crucible, attacks the vitreous matter, and a large quantity of fluoride of silicium is disengaged. The material is stirred from time to time with the platinum spoon, and when the glass is entirely dissolved, the crucible is gently heated, to drive off the excess of acid and evaporate the water; sulphuric acid is then poured upon the residue, completely to expel the fluohydric acid and convert all the oxides into sulphates. When the greater part of the sulphuric acid has been driven off by heat, the substance is treated with water, which leaves the silex and sulphate of lead as a residue. The liquid is filtered and an excess of carbonate of ammonia added, which precipitates the alumina, the lime, the oxide of iron, a part of the oxide of manganese, and the magnesia; an addition of a small quantity of sulphydrate of ammonia completes the precipitation of the manganese. The liquid, when filtered, contains only the alkaline salts, a small quantity of magnesia, and salts of ammonia; it is evaporated to dryness, the residue calcined at a strong red heat, and the alkaline bases are weighed in the state of sulphates. The magnesia is overlooked for the moment, until the termination of the analysis; the potassa is separated by perchloride of platinum, and the soda is determined by calculation from the difference obtained. The magnesia must be sought in the solution remaining after the precipitation of the double chloride of potassium and platinum. The platinum is then precipitated by sulphydrate of ammonia, and the liquid, filtered with an excess of carbonate of soda, is evaporated; the carbonate of magnesia is then separated by treatment with water. This base may also be precipitated by phosphate of ammonia. A much better method of separating the magnesia from the alkalies is the following, when the bases can easily be obtained as chlorides;—The liquid containing magnesia and the alkalies is evaporated to dryness in a platinum crucible, after having condensed its volume by evaporation in a porcelain capsule, out of which the very concentrated solution is carefully washed, with as little water as possible, into the platinum vessel; a small quantity of pure red oxide of mercury is then added, and the crucible subjected to a strong white heat over a spirit lamp, until all the mercury is volatilized. Care must be taken not to inhale the fumes. The magnesia, then all remaining as insoluble caustic magnesia, is separated by filtration from the alkalies, which then may be determined by weighing them together, determining the potassa by precipitation with chloride of platinum, and finding the weight of the soda by the difference. Phosphate of soda, with the addition of some ammonia, effects the precipitation of magnesia much more perfectly than phosphate of ammonia.

GOLD. FR., *Or*; GER., *Gold*; ITAL., *Oro*; SPAN., *Oro*.

Gold is found almost over the whole globe, but in most cases in small quantities compared with other metals. At the present time California affords the largest amount of this metal in the world. Gold is chiefly found in its native condition, in a metallic state, alloyed with silver, and sometimes with tellurium, as is the case in Virginia and North Carolina. In California it is found chiefly in alluvial ground, bedded upon rock in most cases; it is also found enclosed in quartz rock, apparently in veins ramifying the rocks of an extensive mountain range. This California gold is obtained chiefly in large grains, and often in lumps of several pounds weight. In the other States of the Union the gold is in very minute fragments, often invisible to the eye if not aided by a lens, only to be detected by crushing and grinding the rock, and washing off the débris. This gold is apparently derived from the decomposition of iron and copper pyrites, chiefly the first; which assertion cannot be objected to, because it is founded in principle that almost all iron pyrites contain gold, that the gold ores of that region are rocks which are coloured by iron, and that this iron is evidently derived from the decomposition of the pyrites. Pyritous ores of this kind are worked which contain no visible gold, or which do not yield gold at the first crushing and washing, but which furnish gold in a succession of amalgamations, performed after regular intervals of exposure to the air in a fine powder.

A splendid yellow colour and brilliant metallic lustre characterizes gold distinctly from other metals; its specific gravity being 19·3 to water, is another quality easily appreciated by the senses. It is pre-eminently ductile, which qualifies it for an extensive use in the arts. One grain of gold may be drawn into a wire 500 ft. long; silver may be coated with gold, of which the thickness is only the twelve-millionth part of an inch, and still the microscope cannot detect the slightest indication of an interruption of the gold coating. Pure gold requires more heat for melting than either silver or copper, but as all native gold is alloyed with some other metal, it may be considered more fusible than those metals. If, in cupelling gold, the hot globule shines with a greenish light, we may consider the gold not much adulterated; if it contains 10 per cent., or from there to one-third of silver, the colour of the gold is in the hot cupel white as silver. Pure gold is not very volatile, and may be exposed to a strong heat for a long time without loss of metal; but if gold is alloyed with volatile metal, such as lead, zinc, and antimony, it is liable to be carried off by their vapours. Gold has a considerable cohesion, which inclines it to crystallization. Its crystal form is an octahedron; it is often found in fragments of crystals imbedded in quartz. In melting gold along with pure borax it assumes a whitish colour, as if adulterated with silver; in melting it again with saltpetre, or common salt, it recovers its rich yellow colour.

The geological position of gold is in the primitive rock. It is found in granite, disseminated in grains and spangles through the mass of rock. In the United States gold is chiefly found in the stratified transition series. Most of the gold, the California gold exclusively, is found in alluvial soil. In the Southern gold region this source is much exhausted, and the gold is here obtained from regular, well-developed veins, running parallel with the general direction of the rock strata, south-west by north-east. The plane of inclination of these veins is also parallel with the plane of inclination of the general formation. It appears from this that the gold-bearing veins are of a simultaneous origin with the rock; at least, they have been introduced when the rock was in a plastic condition. In Virginia and North Carolina the gold-bearing veins are a ferruginous talcose slate, often inclined to mica slate. In North Carolina this slate is found to be very hard in many instances, showing a compact solid mass of rock, apparently the same slate; but having been under the influence of a considerable heat, it is hardened. In Virginia this slate is more soft, the fissures open more readily, and the whole vein shows the appearance of soft slate. This slate is impregnated with small quartz veins, from ⅛ to ½ an inch, and often 2 in. thick. Where these quartz veins are thin and in great numbers, the ore is always found to be richest in gold. The veinstone of the gold-bearing veins is strongly impregnated with oxide of iron, showing evidences that this iron is derived from pyrites, because the oxide appears in dots or flowers, and groups of dots. Many of these veins have been traced to that depth where the pyrites are not oxidized; here they appear in their perfect crystal form, and are profusely distributed through the slate. The oxidation of these pyrites appears to depend on the penetrability of the rock by atmospheric agents; where the slate is soft we find it oxidized to the depth of from 50 to 150 ft.; where the slate is hard, as is the case at the Sawyer Mine, North Carolina, the oxidation reaches hardly 10 or 20 ft. deep, and is in many places, such as bluffs, not developed at all. At the latter spots the pyrites are in their original form, untouched by oxygen. Where the pyrites are not oxidized, the extraction of gold is connected with considerably more expense than it is from soft slate and oxidized pyrites. The crushing of the hard slate is in the first place more expensive; the sulphur of the pyrites destroys a large portion of quicksilver in amalgamation, and the gold cannot be all extracted; the largest portion of it remains enclosed by the sulphuret of iron, which can only be liberated by destroying that envelope.

There is, however, one drawback to the rapid extraction of gold from deposits—the ores are all, without exception, pyritous in greater depth, and to work these sulphurets to advantage no progress has been made up to this time. Various experiments tending to accomplish this purpose, and affording means of extraction, have been tried, but none of these succeeded so far as to work the poorer class of ores. At Goldhill, N.C., where the ores yield from $1.50 to $3 of gold in 100 lbs. or one bushel of ore, the pyritous ores are ground, amalgamated, and a certain portion of gold extracted. The crushed ore, now a fine sand, is exposed to the influence of the atmosphere for one year, after which the process of grinding and amalgamating is repeated, and another portion of gold, almost equal to the first, is extracted. An exposure of another year furnishes another crop of gold, which operation may be repeated four or five times without extracting all the metal from the sand. This way of working is tedious, expensive, and will not answer where the ores yield but 25 cents to the bushel. The process of roasting these ores by artificial fire is too expensive, and all processes which require much labour are out of the question.

The extraction of gold is performed in California, and also in some parts of the Southern States, simply by washing the alluvial soil, removing the sand, clay, and débris of rock; after these operations the gold, as specifically the heaviest matter, will remain in the vessel in which the washing has been performed. This washing may be done to advantage in a tin pan or a sheet-iron pan. Such a pan is filled with sand containing the gold, and immersed in water; in stirring it gently by hand the clay and light sand flow off, and, after some of the earthy matter is removed, the pan is shaken so as to bring the heavier gold to the bottom of it; the superstratum of sand is now removed, and the gold found in the bottom of the pan (see p. 265).

Gold enclosed in rocky matter cannot be washed with success in the foregoing described manner; the rock must be crushed, and is, in this operation, transformed into more or less fine sand. The bulk of this sand is removed by washing, and the rest, with the gold, reserved for amalgamation.

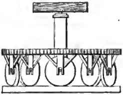
The crushing is performed in the stamp-mill (p. 272).

After the crushing is performed, the sand, including gold, is conducted over hides, which retain the gold, and the sand is floated away. The gold and sand from the hides are removed, when the latter are filled, to an amalgamating machine, which combines the gold with quicksilver, and admits the sand to flow off. Instead of hides, woollen blankets are also used for gathering the gold, and there is a diversity of opinions as to the merits of either. Blankets, it is contended, are more expensive than hides, but they have the advantage of working more uniformly. Hides are cheaper, but they lose their hairs or wool very soon, and are then not fit to do good work. Hides of short, curly wool are selected; these are spread on the ground, and over these the water, sand, and gold are led in a broad sheet. In other instances, shaking tables are suspended at the discharge of the stampers, which gather the gold and some sand. Shaking tables are wooden platforms of 8 or 10 ft. long, and from 3 to 4 ft. wide, made of 2-in. plank well joined together, and the whole smoothly planed. Around the edges of the table are projecting ribs, which prevent the water from flowing over the edges. In suspending this table, a little inclined to the horizontal, leading the sand and water over it in a broad sheet, and applying a gentle shaking motion to it, the gold will sink to the bottom and move gently down the plane; it is arrested at the lowest end of the table by a projection on the table. In either of the above cases the gold is brought to the amalgamating machine for amalgamation.

Most of the gold-mining establishments are provided with Chilian mills for crushing the ore. There are some machines of this kind in North Carolina, which work by four or five runners or crushers in one trough.

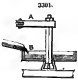
In Fig. 3300 such a machine is represented as it is in operation at Goldhill. It is a cast-iron circular trough of about 16 ft. diameter, 10 in. wide, and 6 in. deep; the trough is firmly fixed upon the floor of the mill. In this trough five travellers, or head-stones, are moving, of 3 ft. diameter and 6 in. thick, rounded on the edge, made of cast iron. These travellers are fixed to the revolving shaft in the centre, and are moved by it. The circular trough is supplied with coarsely-broken ore and a constant current of water, which latter washes off all the light impurities, and leaves the gold in the trough. At the close of every day's work the trough is supplied with some quicksilver, which is worked in it for ¼ or ½ hour's time, in which time it absorbs the gold, and is then removed as amalgam. The water from these mills is generally conducted into other machines, in which some of the fine gold which passes from the first machine is gathered. In most cases a shallow round basin, of about 4 ft. diameter, is appended, in which a rake moves around with a vertical axis, gently stirring the sediment which may settle from the passing water. It retains only the heavy particles. In other instances Sullivan bowls (a small machine which derived its name from the inventor) are appended; these gather the heavy parts which may escape the previous machines.

3300.

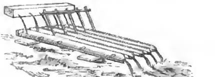


A Sullivan bowl is represented in Fig. 3301. A vertical wooden shaft, of about 18 in. long and 2 in. square, carries on the lower part a shallow vessel or bowl B, about 2 in. deep and 18 in. in diameter. This bowl is formed of a wooden bottom and sheet-iron periphery. The bowl receives the water from the other machines at or near its circumference, and discharges at the centre. By the lever A the machine is set in a rocking motion, caused by a crank connected with the same. The machine gathers a great deal of fine gold, but it is an expensive machine, because it works but little water, and it requires many machines to do the work of a small establishment.

3301.



3302.



The gold from the various machines, mixed with some sand and other impurities, is carried to the Chilian mill for amalgamation, in case there is no other machine for doing that work. This is an imperfect machine for amalgamation, and causes losses in quicksilver and gold. In most cases separate machines are used for amalgamation; in North Carolina the cradle is generally employed. The cradle is made from the trunk of a tree, hollowed out so as to form a round trough, closed at one end and open at the other, as represented in Fig. 3302.

Here is a battery of five cradles represented; as many as that are frequently connected and moved by a little boy. A cradle is from 10 to 12 ft. long, hollowed out of a trunk of at least 24 in. diameter. The bottom part is thicker than the sides. The first cradle in the drawing shows a section. We see here three or more grooves carved in the bottom; in each of these grooves from 3 to 4 lbs. of quicksilver are put. At the farthest end sand is shovelled in and water led upon it, the cradles being a little inclined towards the discharge. A gentle current of water will have a tendency to wash sand and everything else down the trough, the trough being, in the mean time, in a rocking motion, which assists the water in washing off everything. The quicksilver in the grooves is also in constant motion, by which the heavy granules of gold gliding down on the bottom are arrested by it, while the lighter matters, as sand, &c., are not attracted, and pass over the mercury. These machines are very effective, but work slow, and lose much of the fine suspended gold. Other amalgamating machines have recently been put in operation; their efficacy is, however, not settled, and we hesitate to describe them. In North Carolina the German barrel amalgamation has been introduced within a few months, but we are not informed of the results. In Virginia, amalgamating machines of novel patterns have been tried, but we are not acquainted with their effects.

All amalgamating machines suffer under a common evil—they cannot work all the water, as it issues from the crushing machines, to advantage. In all instances half the golden contents of the ore are lost. This is owing partly to the clayish condition of the ore, which clay encloses particles of gold, and carries it off, and partly to the extreme division of the gold in the ores of these regions, particularly in North Carolina. This minute division causes the gold to be suspended in water, and in that condition it is carried away by the current. A good amalgamating apparatus, which will work the water directly from the crushing machines, rub off clay and other matter from the particles of gold, so as to make it adhere to the quicksilver, and which does not lose any quicksilver, is still a desideratum in the Southern gold-mining districts.

Gold gathered by quicksilver forms a white amalgam. In the amalgamating machines a surplus of quicksilver is used to secure the fluidity of the mercury; for if it gets slimy, or, still worse, plastic, like clay, it will not absorb any more gold with facility. The fluid amalgam is pressed through a soft leather or a piece of close canvas, to remove the superfluous mercury, after which a solid amalgam, called quick, remains in the bag. The quicksilver which passes through the bag retains always some gold in solution, the quantity of which varies according to the stuff through which it has been squeezed. The amalgam thus obtained contains from 30 to 70 per cent. of gold, according to the mode of working and the quality of the ore. The quick from the Chilian mills generally contains but from 30 to 40 per cent. of gold, while that from stampers contains seldom less than 40, and in most cases from 50 to 60 per cent. of gold. This circumstance appears to speak in favour of the stamps; the difference in the contents of gold, in the amalgam, is owing to its division; the finer the gold, the less of it the amalgam contains. The dry amalgam is distilled in an iron retort, lined with clay; a red heat will drive off the mercury, which is condensed by leading it into cold water. The gold remains in the retort in the form of a powder, which is collected, melted in a crucible along with some saltpetre, and cast into iron moulds, forming square bars of about 1 lb. weight each. One pennyweight of gold of the Virginia mines is generally worth from 90 to 92 cents. North Carolina gold contains more silver than the first, and a pennyweight is seldom more than 90, and in the majority of cases from 80 to 90 cents to the pennyweight. California gold ranges from 75 to 90 cents.

The gold in gold coin and jewellery is never pure, being alloyed with a certain quantity of copper and frequently of silver, to give it a greater degree of hardness. In order to obtain pure gold, gold coin is dissolved in aqua regia, and the solution being evaporated to dryness, by gentle heat, to drive off the excess of acid, the residue is treated with water, by which means the silver is separated as insoluble chloride. An excess of protosulphate of iron, which precipitates the gold in the metallic state, in the form of brown powder, is then poured into the liquid, the reaction ensuing according to the following equation;—$Au_2Cl_3+6(FeO,SO_3)=2Au+2(Fe_2O_3,3SO_3)+Fe_2Cl_3$.

The precipitate is digested with weak chlorohydric acid, and, after being well washed, is fused in an earthen crucible with a small quantity of borax and saltpetre. The protosulphate of iron may be replaced by sesquichloride of antimony Sb_2Cl_3 dissolved in an excess of chlorohydric acid; the sesquichloride of antimony being converted into the perchloride Sb_2Cl_5, while the gold is precipitated in the metallic state.

Gold has a characteristic yellow colour, and its density is 19·5. It fuses at a strong white heat, or at about 2200° of the air thermometer, giving off sensible vapours at a very high temperature. A gold wire is converted into vapour when traversed by the current of a powerful electric battery; and if this take place over a sheet of paper placed at a small distance, the paper becomes coloured of a purplish brown, by the very finely divided gold which is precipitated on it. A blade of silver substituted for the paper soon becomes gilded. A globule of gold gives off vapour very copiously when held between two pieces of charcoal terminating the conductors of a powerful galvanic battery.

Gold is the most malleable of all the metals, and when beaten into very thin leaves is transparent, the transmitted light appearing of a beautiful green colour. Gold may be crystallized by fusion, when it assumes the shape of cubes modified by other facets of the regular system. Native gold is sometimes found in well-defined crystals presenting the same form.

When precipitated in a metallic state from its solutions, gold forms a brown powder, which by burnishing soon recovers the metallic lustre and characteristic colour of malleable gold, and which aggregates by percussion. If the mass be heated to redness before being hammered, a perfectly aggregated metal can be obtained without having heated it to fusion.

Gold does not combine directly with oxygen at any temperature. Chlorohydric, nitric, and sulphuric acids do not affect it, while aqua regia, on the contrary, readily dissolves it in the state of sesquichloride, Au_2Cl_3. Gold is also dissolved by chlorohydric acid when a substance capable of disengaging chlorine is added, such as peroxide of manganese, chromic acid, &c. Chlorine and bromine also attack gold, even when cold, while iodine acts on it but feebly.

Sulphur does not attack gold at any temperature, nor does the metal decompose sulphydric acid; but by fusing it with the alkaline polysulphides it is powerfully acted on, a double sulphide being formed, in which the sulphide of gold Au_2S_3 acts the part of a sulphacid. Arsenic when assisted by heat combines with gold, and forms a very brittle alloy.

Gold is attacked neither by the alkalies nor the alkaline carbonates or nitrates.

Compounds of Gold with Oxygen.—Two combinations of gold with oxygen are known;—

1. A suboxide Au_2O,
2. A sesquioxide Au_2O_3,

neither of which forms salts with the oxides.

The suboxide Au_2O is obtained by decomposing the chloride Au_2Cl by a dilute solution of potassa, in the shape of a deep violet-coloured powder, which decomposes at about 77°, disengaging oxygen. The oxacids exert no action on this substance, while chlorohydric acid decomposes it, forming sesquichloride of gold Au_2Cl_3, while metallic gold is separated.

Sesquioxide of gold (often called *auric acid* on account of its property of combining with bases) is prepared by digesting a hot solution of sesquichloride of gold with magnesia, when aurate of magnesia is formed, which remains mixed with the free magnesia. The deposit is boiled with nitric acid, which dissolves the magnesia and leaves hydrated sesquioxide of gold. Auric acid may also be obtained by saturating a solution of sesquichloride of gold by carbonate of soda, and then boiling the liquid, when a large proportion of the gold is precipitated in the state of sesquioxide, while the other portion remains in solution, but may be precipitated by successively adding to the liquid an excess of caustic potassa and acetic acid.

Hydrated auric acid is a yellow or brown powder, which loses its water at a low temperature and becomes anhydrous, while at about 482° it decomposes into gold and oxygen, which reaction is also effected by the solar light. Deoxidizing substances, such as the organic acids, or boiling alcohol, reduce it to the metallic state; while chlorohydric acid dissolves it and produces the sesquichloride Au_2Cl_3. The most energetic oxacids do not form definite compounds with sesquioxide of gold, while the latter dissolves, on the contrary, readily in cold alkaline solutions, producing alkaline aurates which crystallize by evaporation.

By adding a small quantity of ammonia to a solution of sesquichloride of gold, a fulminating substance is produced, which contains, at the same time, oxide of gold, ammonia, and chloride, and which, by digesting with an excess of ammonia, furnishes a bright brown powder of still higher detonating properties than the first, and which is a simple combination of sesquioxide of gold with ammonia $Au_2O_3+2NH_3+HO$.

Compounds of Gold with Sulphur.—Although sulphur does not combine directly with gold, two sulphides corresponding to the two oxides are obtained by decomposing the sesquioxide of gold by sulphydric acid, which, on being passed through a cold solution of sesquichloride of gold, yields a brownish-yellow precipitate, which is the sulphide Au_2S_3, readily soluble in the alkaline sulphides. If the solution of the chloride is boiling, a sulphide Au_2S, of a deep brown colour, is precipitated, while sulphuric and chlorohydric acids are formed $2Au_2Cl_3+3HS+3HO=2Au_2S+6HCl+SO_3$.

Compounds of Gold with Chlorine.—By dissolving gold in aqua regia a yellow solution of sesquichloride of gold Au_2Cl_3 is obtained, which, when allowed to evaporate slowly in dry air, deposits yellow crystals of a compound of sesquichloride of gold and chlorohydric acid. If the solution be evaporated to drive off the excess of acid, the substance assumes a brown colour, and a deliquescent crystalline mass remains, which dissolves readily in alcohol and in ether. Sesquichloride of gold dissolves even more rapidly in ether than in water; for, if an aqueous solution of the chloride be shaken with ether and water, the supernatant ether contains nearly all the chloride of gold in solution. The solution of sesquichloride of gold in ether was formerly used in medicine under the name of *aurum potabile*.

Sesquichloride of gold forms with other metallic chlorides double crystallizable chlorides, in order to obtain which it is sufficient to mix and evaporate the solutions of the two chlorides. The formula of the double chloride of gold and potassium, which is deliquescent, is $KCl+Au_2Cl_3+5HO$, while the formula of that of gold and sodium is $NaCl+Au_2Cl_3+4HO$, and that of the double chloride of gold and ammonia is $NH_3HCl+Au_2Cl_3+2HO$. Compounds of chloride of gold with the chlorides of barium, calcium, manganese, iron, zinc, &c., are also known.

Subchloride of gold Au_2Cl is prepared by heating the sesquichloride of gold Au_2Cl_3 to a temperature of about 400°, when chlorine is disengaged, while a greenish insoluble powder remains.

Compound of Gold with Cyanogen.—By adding a solution of cyanide of potassium to a concentrated hot solution of perchloride of gold, until the liquid loses its colour, a solution is obtained, which, on cooling, deposits prismatic crystals of a double cyanide of gold and potassium of the formula $KCy+Au_2Cy_3$. The crystals, which are efflorescent and very soluble, disengage cyanogen when subjected to moderate heat; and when treated with water, a solution is obtained, which, on cooling, deposits a double cyanide of the formula $KCy+Au_2Cy$.

The name of *purple of Cassius* is given to a precipitate containing gold, tin, and oxygen, which is used by painters on porcelain and glass, and is prepared in various ways. Its composition not being always uniform, chemists are not yet agreed upon its nature. It is generally obtained by pouring into a sufficiently dilute solution of sesquichloride of gold, a mixture of protochloride and bichloride of tin, the precipitate showing a beautiful purple hue when it is of small bulk, while it assumes a brown colour when more copious.

A purple of Cassius of uniform composition is prepared by dissolving 20 grammes of gold in 100 grammes of aqua regia made of 20 parts of nitric and 80 of chlorohydric acid; driving off the excess of acid by evaporation in a water-bath and dissolving the residue in 7 or 8 decilitres of water. Some pieces of tin being placed in the liquid, a purple precipitate of the formula $Au_2O, SnO_2+SnO, SnO_2+4HO$ is formed, but which may also be considered as $2Au+3SnO_2+4HO$. The substance, on being subjected to heat, evolves water alone and no oxygen, while the calcined residue presents all the characters of a mixture of metallic gold and stannic acid. But as before calcination the substance will not give off gold to mercury, it is evident that the gold did not exist in it in the metallic state.

A beautiful purple of Cassius is obtained by heating suboxide of gold Au_2O with a solution of stannate of potassa.

Lastly, purple of Cassius is obtained by fusing together in a crucible 1 part of gold, ½ part of tin, and 4 or 5 of silver, forming a ternary alloy, from which nitric acid extracts the silver, while the gold and tin are precipitated in combination with oxygen, and a brilliant purple is formed, the shades of which can be changed by altering the relative proportions of gold and tin.

A solution of sesquichloride of gold stains linen of a purple colour, as it also does the skin and the organic tissues generally, which colouring is probably owing to suboxide of gold, as friction does not restore a metallic lustre to the spots, although they acquire it in a short time when exposed to solar light in a bottle filled with hydrogen gas.

Determination of Gold, and its separation from other metals.—Gold is always determined in the metallic state, and is precipitated from its solutions by means of protosulphate of iron, after having added chlorohydric acid to the liquid in order to maintain the sesquioxide of iron which forms during the reaction in solution. But it is important, in order to completely precipitate the gold, that the liquid should contain no nitric acid; in which case it must be previously evaporated with chlorohydric acid. The gold, when collected on a filter, is calcined to redness before being weighed.

In order to separate gold from the metals previously described, the insolubility of the metal in nitric acid is sometimes relied on, while at other times all the metals are dissolved in aqua regia, and the gold is precipitated by protosulphate of iron, or, better still, by heating the solution with a certain quantity of oxalic acid; which latter method has the advantage of not introducing a new metal into the liquid. Gold is sometimes also separated by precipitating it in the state of sulphide, by sulphydric acid gas, the sulphide leaving metallic gold after calcination.

Metallurgy of Gold.—Gold is almost always found in the native state, being sometimes pure, but more generally alloyed with certain quantities of silver. It occurs in three kinds of bearings;—

1. In veins, generally quartziferous, which contain other metallic minerals, as ores of copper, lead, silver, and pyrites; the veins usually traversing the primitive rocks.

2. In small veins scattered through rocks situated at the separation of the crystalline and stratified rocks.

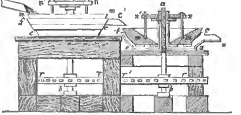
3. In disaggregated quartzose sands, often extensively seen in alluvial formations, and owing their presence to the disintegration of auriferous crystalline rocks which exist in the vicinity. The greater specific gravity of the gold prevents its particles from being carried as far as those of the other minerals with which it is mixed, and its resistance to the action of the greater part of chemical agents preserves it in the state of spangles. Alluvious soils containing gold chiefly occur in open valleys between primitive mountains, where gold is frequently found in place. The principal localities of auriferous sands are in California, Australia, Brazil, Mexico, Chili, Africa, the Ural and Altai Mountains in Siberia—the quantity of gold annually extracted from all of which amounted, in 1851, to 178 tons, of which California alone produced 110. Gold is generally found in the sands in the form of spangles, or shapeless and rounded grains, which, when they are of any considerable size, are called *river* or *wash gold* (pépites). Grains are sometimes found of the size of a hazel-nut, and pieces weighing several kilogrammes have been met with; one lump weighing 36 kilogrammes was found in the Ural. Gold exists in the drift-sand of all rivers which arise from or flow over a large extent of primitive rocks; and several auriferous alluviæ are known in France, such as those of the Ariége in the Pyrenees, of the Gardon in Cevennes, the Garonne, and the Rhine, near Strasburg. It is found in too small quantity to be worked to advantage; but the inhabitants look for it when they would otherwise be idle, and are then called *gold-finders*. The spangles of gold scattered through the river-sand are generally so excessively small that more than twenty are often required to make a milligramme. In Siberia, sands containing only 0·000001 of gold are not considered worthy of being worked; and the Rhenish sands contain, on an average, about ¼ of this quantity. Gold exists also, combined with tellurium, in certain mines of Transylvania. An alloy of gold with silver and palladium, in the form of small crystalline grains, occurs in Brazil, and is called *auro-powder* or *auro-dust*. Lastly, all pyrites in primitive rocks contain a small quantity of gold, and are often rich enough to be worked to advantage.

When gold exists in veins which contain other metals, as lead, copper, or silver, those metals in which the gold is concentrated are first extracted from the ores, and the gold is then separated by *refining*, a process presently to be described. The ore is frequently first subjected to amalgamation, as in the case of silver ores, when the gold dissolves in the mercury, and, after the liquid amalgam has been filtered, a more solid amalgam is obtained, from which the gold is separated by distillation. The ore is then smelted, so as to obtain a matt from which a certain quantity of gold can still be extracted.

Auriferous sands are washed in the most simple manner, either in wooden tubs, or on inclined planes over which a current of water flows, and they are then treated by amalgamation. In the Ural, the auriferous sand is poured into boxes, the sheet-iron bottom of which is provided with openings of 2 centimètres in diameter, and, while a stream of water flows through the boxes, the workman stirs the sand constantly with a shovel, when the finer portions fall through the holes and are collected on large sleeping tables covered with muslin. The sand is frequently swept toward the head of the table, where the gold remains with the heavier minerals; and the sand, being enriched by this washing, is again more carefully washed on smaller tables. The titanic iron and magnetic oxide of iron being separated by a magnet, the material is fused in large graphite crucibles, at the bottom of which the gold collects, while the upper part is filled by a slag containing a quantity of unmelted grains of gold. The slag being stamped and washed, the rich schlich thus obtained is smelted, yielding an auriferous lead, from which the gold is separated by cupellation.

In Tyrol a certain quantity of gold is extracted from pyrites by amalgamating them in mills resembling that represented in Fig. 3303, several mills being generally placed above each other. (The figure gives an external view of the upper mill and a section of the lower one.) The pyrites, in the state of an impalpable powder, is suspended in water, and conveyed into the upper mill by the conduit G, whence it flows into the second mill by the sluice G′. The bed of each mill is made of a cast-iron vessel *c d e f*, securely fastened on a strong wooden table; and in the centre of the vessel is a tubulure traversed by an axis of rotation *a b*, set in motion by the cog-wheel *r r′*. The runner-stone *m m′* of each mill is of wood, and resembling the shape of the bed; but being about 2 centimètres smaller, is furnished with several sheet-iron teeth projecting about 1 centimètre. The upper surface of the runner-stone is shaped like a funnel, into which is poured the liquid mud, which passes between the stones and flows out by the conduit G′. The stones make about

3303.



fifteen or twenty revolutions a minute; and 25 kilogrammes of mercury are placed at the bottom of each, making a layer of about 1 centimètre in thickness, against which the teeth of the wheel constantly strike, while at the same time they stir up the ore. The gold is dissolved by the mercury, and, after continuing this process for four weeks, it is withdrawn and filtered through a chamois skin, which retains a solid amalgam containing nearly one-third of its weight of gold, which is then separated from the other metals by cupellation.

Alloys of Gold.—Gold is rarely used in a state of purity, as it is too soft, and its hardness must be increased by the addition of a small quantity of silver or copper, forming more fusible alloys than pure gold.

The standard of French pure gold coin is $\frac{900}{1000}$, the law allowing a variation of $\frac{2}{1000}$ above and $\frac{2}{1000}$ below; while medals contain 0·916 per cent. of gold, with the same variation. There are three legal standards for jewellery, the most common of which is $\frac{750}{1000}$, while those of $\frac{840}{1000}$ and $\frac{920}{1000}$ are rarely used; and the legal variation is $\frac{3}{1000}$ below the standard, no superior limit being fixed.

Gold is soldered with an alloy called *red gold*, of 5 parts of gold and 1 of copper; an alloy made of 4 parts of gold, 1 of copper, and 1 of silver also being used.

The clear colour of gold is given to jewellery by dissolving the copper which exists in the superficial layer; to effect which the articles are heated to a dull red heat, and dipped, after cooling, into a weak solution of nitric acid, which dissolves the copper. A thicker coating of pure gold is obtained by allowing them to remain for fifteen minutes in a paste formed of saltpetre, common salt, alum, and water; the chlorine set free by the action of the sulphuric acid on the salt and saltpetre dissolving the copper, silver, and gold, while the latter metal is again deposited on the article. The surfaces are then burnished.

Separation of Gold and Silver.—The separation of gold and silver, more generally called the *refining of the precious metals*, is now done by treating the alloy by concentrated hot sulphuric acid, which dissolves the silver only. But in order that the alloy may be completely acted on, it should neither contain more than 20 per cent. of gold, nor than 10 per cent. of copper, because sulphate of copper is but slightly soluble in concentrated sulphuric acid. The alloys are fused in crucibles, and when they are too rich in gold, a certain quantity of silver is added—silver containing a small quantity of gold being preferred. The fused alloy is granulated by being poured into water, and then placed in a large kettle with 2½ times its weight of concentrated sulphuric acid marking 66° on the areometer, the kettle being covered with a lid furnished with a disengaging tube. The acid, being heated to boiling, is partly decomposed, and sulphates of silver and copper are formed, while sulphurous acid is disengaged, which is sometimes passed into the leaden chambers where sulphuric acid is manufactured. When gold coin is to be refined, it is merely roasted.

After four hours, when the alloy is completely destroyed, there is introduced into the kettle a certain quantity of sulphuric acid marking 58°, and obtained by the concentration of the acid mother liquid of the sulphate of copper obtained in refining, as will presently be explained. After having boiled the liquid for fifteen minutes, the kettle is taken from the fire and allowed to rest, when the greater part of the gold collects at the bottom of the vessel, from which the nearly boiling liquid is decanted off into leaden boilers containing the mother liquid arising from the purification of the sulphate of copper by crystallization. The boilers are heated by steam; and after the sulphate of copper at first deposited is redissolved, the liquid is allowed to rest for some time, when the whole of the gold is deposited. The clear liquid is then drawn off by a siphon, and passed into other boilers heated by steam, and containing blades of copper, which precipitate the silver in the form of small crystalline grains; the metal being in a short time so perfectly precipitated that the liquid is not clouded by common salt. The precipitated silver is carefully washed, and then compressed by an hydraulic press into compact prisms, which, after being dried, are melted in earthen crucibles, furnishing a metal which contains only a few thousandths of copper.

As the gold arising from the first action of the sulphuric acid still contains a certain quantity of silver, it is heated anew, in a platinum crucible, with concentrated sulphuric acid, which abstracts the balance of the silver; a third treatment with sulphuric acid being often required. The gold dust, after being well washed and fused, contains 995 thousandths of pure gold.

The acid solution of sulphate of copper which arises from the precipitation of the silver by copper is evaporated in leaden kettles until it marks 40° on the areometer; a large proportion of the sulphate of copper being deposited in small crystals during the cooling. After another evaporation, the mother liquid yields an additional quantity of crystals; and the last liquid, which refuses to crystallize, is used as a solution of sulphuric acid, and poured into the cast-iron boiler, after this action on the alloy. The sulphate of copper is purified by recrystallization.

When the quantity of gold and silver contained in an alloy does not exceed 0·200 or 0·300, the granular material is first heated in a reverberatory furnace, when a portion of the copper is converted into oxide, which is dissolved by treating the roasted substance with weak sulphuric acid; and the alloy, being thus brought to the medium standard of 0·500 or 0·600, may be refined by the ordinary process. The process of refining gold pursued at the United States Mint, in Philadelphia, is similar to the method formerly called quartation, and consists in melting gold with silver, and then extracting the silver with pure nitric acid. The deposit of grains of native gold is first melted with borax and saltpetre, occasionally with soda to remove quartz, and being cast into a bar, is carefully weighed, accurately assayed to $\frac{1}{5000}$ for gold, and from the assay and weight the value of the deposit is calculated. Although a million of dollars may be deposited in a day, upon an arrival from California, yet such is the expedition of the assay department, that in a few days the deposits are all paid off. As soon as the gold is assayed, each lb. of it is melted with 2 lbs. of pure silver, and the mixture, after stirring, poured into cold water, by which it is *granulated*, divided into small irregular fragments, presenting a large surface to the subsequent action of the acid. The granulations are then put into large porcelain jars of 50 gallons each, of which there are about seventy in use, and nitric acid poured in them. The jars being placed in leaden-lined wooden troughs, containing water, are heated by a steam coil in the water, causing the nitric acid to dissolve out the larger proportion of silver. A steam heat is given during several hours, and the liquid allowed to repose until the following morning, when the solution of nitrate of silver is drawn off by a gold siphon, and transferred to a large vat of 1200 gallons, containing a saturated solution of common salt. Fresh acid is then added to the gold in the pots, already nearly parted, steam heat applied again for several hours, and the whole left again to repose. On the following morning the acid liquid of one of the pots being drawn off and the fine gold removed to its filter, fresh granulations of gold and silver are introduced, and the acid liquid of the adjoining pot, containing only a small quantity of nitrate of silver, poured over it. A fresh charge of granulated metal is thus first worked by the yet strong acid, which acted on the nearly fine gold of the previous charge. A charge of $800,000 or more is easily worked off, *refined*, in two days, by 4½ lbs. of parting acid to every lb. of gold. The gold is washed thoroughly on a filter by hot water, pressed in a hydraulic press, further dried, melted with copper, and cast into bars, about 2400 ozs. troy constituting a melt. After being assayed, they are then remelted with the calculated quantities of copper or fine gold requisite to bring them to a standard of 900 thousandths fine, and cast into ingots. Upon their proving correct in the assay, usually to within $\frac{1}{1000}$ of the standard, they are delivered to be coined. The chloride of silver, accurately precipitated with a slight excess of salt, is filtered and washed thoroughly on large filters, of 3 ft. by 5 ft., and 14 in. deep. It is then transferred to lead-lined wooden vats, reduced to metallic silver by granulated zinc, and, the excess of zinc being removed by sulphuric acid, washed, pressed in the hydraulic press, dried by heat, and remelted with a new portion of gold.

This method of parting formerly required 3 parts of silver to 1 part of gold, and the latter constituting a fourth part of the alloy, the process was termed *quartation*. We have, however, found that 2 parts of silver to 1 part of gold are quite sufficient; and if the metal be well granulated, the acid will not leave 10 thousandths of silver in the gold, which is sufficient to prevent the too darkening effect of copper in the coin.

Analysis and Assaying of Alloys of Gold.—Alloys of gold and copper may be analyzed by cupelling them with lead, and following exactly the same process as described for the cupellation of alloys of silver and copper. If the alloy contains no silver, the weight of the lump obtained represents pretty exactly the quantity of pure gold which existed in the alloy; but if, as more frequently happens, the alloy contains a certain proportion of silver, this latter metal remains alloyed with the gold after the cupellation. However, the process of direct cupellation is attended with surpluses and losses which sometimes reach 3 thousandths. When the temperature of the muffle is very great, there is a small loss arising from the absorption of a small quantity of gold by the cupel; and when the heat is too low, the gold retains a small quantity of copper and lead; although gold loses less by volatilizing than silver.

In order to determine exactly the quantity of gold existing in a ternary alloy of gold, silver, and copper, it is cupelled at a moderate heat with a certain quantity of silver and lead, in order to obtain an alloy of silver and gold, from which the latter can be perfectly separated by means of an excess of nitric acid, which dissolves the silver and leaves the gold pure. In order, however, to ensure exact results, there must be a certain ratio between the quantities of gold and silver; because, if the proportion of silver be too small, the nitric acid does not dissolve it entirely; and if, on the contrary, the quantity of silver be too great, the silver and copper are completely dissolved, while the gold separates in the form of powder, which it is difficult to collect without loss. Experience has shown that the most favourable conditions for the assay, commonly called the parting (*départ*), consist in reducing the alloy to ¼ of gold and ¾ of silver, in which case it is completely acted on, while the separated gold preserves the form of the original alloy, and does not become divided, if the operation be carefully conducted. This operation has received the name of *quartation*.

The proportion of lead to be added, which varies with the standard of the alloy, is indicated in the following Table:—

Standard of gold alloyed with copper.	Quantity of lead necessary to be added, to entirely remove the copper by cupellation.
1000 thousandths	1 part.
900 „	10 parts.
800 „	16 „
700 „	22 „
600 „	24 „
500 „	26 „
400 300 200 100 „	34 „

Let us suppose that the standard of a piece of coin is to be determined, the legal standard of which, which may be regarded as its approximate standard, is $\frac{900}{1000}$. The quantity of alloy usually operated on being 0·500 gramme, containing according to the legal standard 0·450 gramme of gold, therefore 1·350 gramme of silver and 5 grammes of lead must be added. But if an alloy is to be assayed, the legal standard of which is entirely unknown, the first step is to ascertain the latter by approximation, by means of the *assay by the touch-needle*, about to be described, after which the process is continued as usual.

The lead is first placed in the heated cupel, and when it is in fusion, the mixture of gold and silver is introduced, having been previously weighed and wrapped in a piece of paper. The cupellation is allowed to go on as usual, and requires less care than the cupellation of silver, because silver alloyed with gold is not liable to blister; but the cupel should be removed immediately after the lighting, to avoid loss by volatilization. The lump is removed after cooling,

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flattened under a hammer, annealed for a few moments, and then rolled between cylinders; after which the sheet thus obtained is rolled into a spiral form, and subjected to the action of nitric acid in a small assayer's flask, Fig. 3304, into which 30 grammes of nitric acid of 22°, Baumé's *Hydrometer*, are poured, and boiled for twenty minutes. The acid is then decanted and replaced by 30 grammes of pure concentrated nitric acid marking 32°, which is boiled for ten minutes; when the acid is decanted, and the gold, which has preserved the shape of the alloy, washed several times. The flask being afterward completely filled with water, its mouth is closed with the thumb, and it is inverted, when the spiral sheet of gold falls slowly through the liquid column, and is received in a small earthen crucible, after which the water is poured off, and the crucible heated to redness in the muffle.

3304.

The acid should not be too concentrated, because the gold might be divided. When the assay has been made with the precautions indicated, the gold remains in the form of a spongy, brown, and very friable mass, of nearly the same volume as the original alloy; but it contracts considerably when heated in the small crucible, becoming harder and assuming the lustre and colour of malleable gold. The calcined gold being exactly weighed, the standard of the alloy is thus obtained within nearly 1 thousandth.

Direct assays made on known alloys of gold and silver have shown that the operation, when carefully performed, as just described, can give rise only to the following errors;—

True standards of the alloy.	Standards found.	Differences.
900	900·25	+0·25
800	800·50	+0·50
700	700·00	0·00
600	600·00	0·00
500	499·50	−0·50
400	399·50	−0·50
300	299·50	−0·50
200	199·50	−0·50
100	99·50	−0·50

The assay just described cannot be applied to fine jewellery, because the article would be destroyed by the process, and gold jewellery is therefore subjected to a test called the assay by the touch-needle, which does not injure it, and yet enables a skilful assayer to determine its standard within nearly 1 thousandth. The method consists in rubbing the object against a very hard black stone, on which it leaves marks, from the colour of which, and their behaviour when moistened with a mixture of nitric acid of a density of 1·34 with 2 per cent. of chlorohydric acid, the assayer forms an approximate opinion of the standard of the alloy. The black stone used, called *touch-stone*, is a kind of quartz, coloured with bitumen, which formerly was imported from Lydia, but has likewise been found in Bohemia, Saxony, and Silesia. The conditions essential to a good touch-stone are;—An intense black colour, incapability of being acted on by acids, hardness, and a sufficient degree of roughness to retain some of the gold.

The assayer is provided with a series of small blades, called *touch-needles*, consisting of alloys of copper and gold, the standard of each of which is exactly known, which enable him to compare the marks they leave on the touch-stone, before and after the action of the acid, with that of the alloys to be assayed.

No regard should be paid to the first marks left by the articles on the touch-stone, as they are made by the superficial layer, and always show a higher standard, because the surface consists of pure gold; and several marks should therefore be made, the last of which only is examined. Alongside of these marks others are made with that touch-needle the composition of which approaches nearest to that of the article; when a glass rod, dipped in the acid, is drawn over both, after which the colour of each mark and the manner of action of the acid are examined.

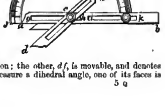
See Alloys. Amalgamating Machine. Amalgamation Pan. Assaying. Atomic Weights. Batea. Battery. Boring and Blasting. Buddle. Drainage. Electro-metallurgy. Founding and Casting, p. 1551. Furnace.

Works on Gold:—J. Calvert, 'The Gold Rocks of Great Britain and Ireland,' 8vo, 1853. S. Davison's 'Gold Deposits in Australia,' 8vo, cloth, 1861. J. Arthur Phillips, 'The Mining and Metallurgy of Gold and Silver,' royal 8vo, 1867. Silversmith, 'Handbook for Miners,' 12mo, New York, 1868. R. B. Smyth, 'The Gold Fields of Victoria,' 4to, Melbourne, 1869. W. P. Blake, 'The Production of the Precious Metals,' 8vo, New York, 1869. Von Cotta, 'Treatise on Ore Deposits,' by Prime, 8vo, New York, 1870. P. M. Randall, 'The Quartz Operator's Handbook,' 12mo, 1871.

GONIOMETER. Fr., *Goniomètre*; Ger., *Goniometer*; Span., *Goniometro*.

Various instruments termed goniometers are employed in the measurement of the angles of crystals. Two kinds are in use—the common or contact goniometer, and the reflecting goniometer. The first class only of instrument is here described, as it will sufficiently answer every purpose of the mining mineralogist. The most simple form of instrument, Fig. 3305, consists of a graduated brass semicircle, on which two metallic cross-blades are fixed. One of these cross-blades, *a b*, is fixed at the zero of the division; the other, *d f*, is movable, and denotes on the circle the angle of the crystal. In order to measure a dihedral angle, one of its faces is

3305.

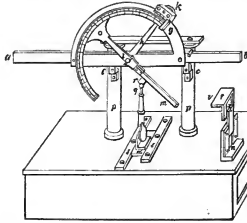


applied to the fixed cross-blade ab, in such a manner that the edge of the angle is perpendicular to the plane of the circle; the movable cross-blade is then adjusted until its prolongation rests upon the outer face of the angle. It is evident that the angle comprised between the two cross-blades, and which is directly indicated on the circle, is the measure of the angle sought.

The two cross-blades $a d$, $d f$, slide in the grooves i K, $g h$, $d n$, so as to admit of the ends $c a$ and $e d$ being made as short as is required. This condition is indispensable, as it is often necessary to measure very small crystals, which can only be introduced easily between the two cross-blades when their free ends can be very much shortened.

This form, however, of the common goniometer has many inconveniences. The observations are rendered difficult from the fact that the crystal under examination has to be held with one hand, and the instrument with the other. Moreover, in holding it before the eye, to ascertain if the cross-blade is in perfect contact with the crystal, continual vacillations and disturbances are produced, which render anything like a correct observation very difficult. These inconveniences are overcome by the use of a fixed instrument. The crystal under examination is also fixed on a support, so that both hands are at liberty. This instrument, Fig. 3306, consists of a semicircle

3306.



fixed on a rod $a b$, supported by columns $p p$. The rod $a b$ can be moved horizontally, from right to left, in the grooves $c c$, in which are placed small friction rollers, so as to render the movement as easy as possible. The fixed semicircle carries another, $f g$, movable on the centre o, and divided into degrees; $h i k$ is a vernier which also moves on the centre, but behind the movable semicircle between it and the fixed, to which it can be at any time fastened, and in any required position, by the thumb-screw k; this vernier gives the minutes. $l m$ is a blade whose movement carries round the circle $f q$; q is a small stem, the function of which is to support the crystal r, which is firmly fastened with wax. It is so arranged that it can be lengthened or shortened, be inclined either from or towards the operator, and capable of turning on itself. It is supported on a small movable platform s, running between the rods $s s$, which form a groove. The piece $t v$, seen on the side of the apparatus, is a sight, which, applied against one of the rods s, when the platform is drawn sufficiently forward, enables the operator to judge if the edge formed by the two faces of the crystal is exactly horizontal, and if it be perpendicular to the plane of the circle.

To measure a crystal it must be firmly fixed on r, and the movable platform brought forward; the sight must now be placed against the rod s, and the upper part raised or lowered as needed; looking from above, it can be seen whether the edge of the crystal is parallel to the edge v, in which case it is perpendicular to the plane of the circle. If the parallelism be not perfect, the rod q is turned on its axis until the proper position is attained. The crystal must then be viewed through the opening x, and the same angle adjusted horizontally, which can be effected by inclining the rod either one way or the other as required.

When the crystal is properly adjusted, the movable platform is pushed under the circle. The blade $l m$ is now to be moved, and at the same time the rod $a b$ is to be pushed either to the right or left as may be found necessary, so that the edge of the blade may be in perfect juxtaposition with the face of the crystal; when this has been accomplished, the vernier is carried to the end of the movable semicircle, where a small cleat stops it exactly at zero; it is then fixed by the screw k.

This done, the platform is drawn from under the circle, and the blade passed in the contrary direction to that which it before occupied; the platform replaced, and the blade brought into juxtaposition with the other face of the crystal; this accurately done, the stem and crystal are removed.

By this second application of the blade to the crystal the semicircle has turned, and the point where it stops indicates the measure of the angle, which is read on it in degrees; the vernier furnishes the minutes.

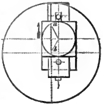
GOUGE. Fr., *Gouge*; Ger., *Hohlmeissel*; Ital., *Sgorbia*; Span., *Gubia*.
See Augers. Hand-Tools.

GOVERNOR, Steam-Engine. Fr., *Régulateur*; Ger., *Regulator*; Ital., *Regolatore*; Span., *Regulador*.

How the action of centrifugal force is utilized in the construction of steam-engine governors is fully investigated in our article, Angular Motion, p. 101.

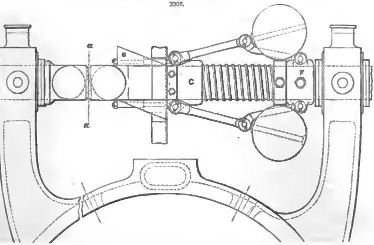
Roby and Richardson's Governor, Figs. 3307, 3308.—This invention consists in mounting the governor on the crank-shaft, with which it revolves, and causing it to act directly upon the slide-valve eccentric, so as to regulate the quantity of steam that shall be admitted during the stroke according to the work done by the engine; and as no throttle-valve is needed, steam can at all times be taken into the cylinder at nearly boiler-pressure, and thus do the same work; a much earlier cut-off is attainable and many advantages gained.

3307.



The eccentric A, Fig. 3307, has a rectangular slot cut in it parallel to a line connecting its two centres of forward and backward motions. The slot *a b* fits over a square part of the crank-shaft, upon which it slides at right angles to the crank by which it is driven. It is held in position on this square by two wedges D E, shown in Fig. 3308. Fig. 3308 also shows the position of the governor on crank-shaft; the boss F is fast on the shaft, while G is free to slide towards F. When the balls expand to this slide G the wedges D E are fixed. When the balls expand by their centrifugal force the wedges are drawn out, and the eccentric slides upward in the direction of the arrow, Fig. 3307. The travel of the valve is reduced, the angle of the eccentric with the crank is altered so as to make the cut-off earlier while the lead remains constant.

3308.

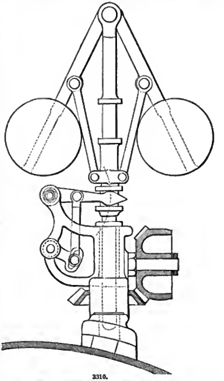


Clayton and Shuttleworth's Governor, Fig. 3309. This is a simple form of centrifugal governor employed both to portable and stationary engines, but especially to the former class of engine. Motion is imparted to the vertical spindle, through the mitre-wheels and pulley by a plain leather belt, from the crank-shaft of the engine. As the speed increases the centrifugal force causes the balls to expand, and through a proper arrangement of links and sliding sleeve, the balls raise the forked lever, which in turn, by means of the link and quadrant, closes the throttle-valve in the steam-pipe, thus instantly checking the speed of the engine. The speed of the engine being checked, the speed of the governor is also checked, and the throttle-valve opened to a corresponding extent. As in ordinary governors, by a proper adjustment of the quadrant, the throttle-valve is set so that the speed of the engine may be rendered uniform under any variation of work.

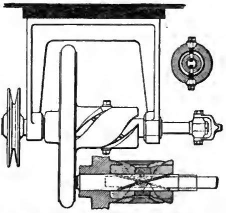
N. P. Burgh, in his useful work on Marine Engineering, observes;—"The changes of speed being so sudden, it is obvious that in designing a governor for a marine engine, such an arrangement should be adopted as would have an action extremely sensitive, powerful, and prompt in affecting the valve. Modifications of the old two-ball governors were first tried, and afterwards balanced four-ball governors. The first failed, as the governing action of the balls was destroyed by the motion of the vessel. With the last, in which the balls are arranged to balance each other in such a way that the action of the instrument is not affected by the same cause, it is apparent that when the sudden acceleration of speed in the engine takes place, the inertness of the balls resisting the sudden motion may prevent the prompt action on the valve.

"Attention being drawn to the subject by this conclusion, a governor, consisting of a fly-wheel loose upon a shaft, was next applied for the purpose. There are several varieties of these governors in use, and the following is an explanation of the governing principle on which the action of most such speed regulators properly depends.

3309.

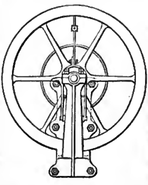


3310.

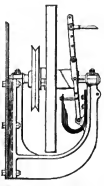


" Presume as an illustration that a fly-wheel is fitted loosely on a shaft driven by a connection with the engine, which shaft rotates with a velocity that varies exactly as the speed of the engine varies. The slight friction resulting from the loose fit of the fly-wheel suffices to impart to it in a short time—almost instantaneously—the same velocity as that of the shaft. Some mechanical contrivance or circuit of connection between the fly-wheel and throttle-valve is so adjusted that, while both shaft and fly-wheel rotate at the same velocity—that is, the normal or proper velocity of the engines—the throttle-valve is held open. But the instant a sudden increase of engine-speed occurs, the relative velocities and position of fly-wheel and shaft are changed, and a differential velocity is created, the revolutions of the shaft becoming a little in excess of those of the fly-wheel, because the slight friction between the shaft and the fly-wheel is not sufficient to impart instantly to the latter the suddenly increased velocity of the former. This advance of the motion of the shaft *shortens* the mechanical circuit of the connection between the fly-wheel and the throttle-valve, and by so operating, closes the valve. Again for exemplification, when from throttling the steam or from other causes a diminution of the engine speed occurs, the revolutions of the shaft are a little below those of the fly-wheel, and the circuit of connection *lengthens* and the valve opens. It is thus evident that the essential means for affecting the valve is, the existence of a differential velocity of the fly-wheel and shaft, and that by this is produced the necessary amount of to-and-fro motion in the mechanical circuit of connection between the fly-wheel and valve. It therefore follows that the more simple the means by which the connection is formed, providing that it be at the same time sufficiently powerful, or capable of easily communicating the result of the differential velocity, the more reliable, sensitive, and efficient will be the regulative action. An example of a wheel-governor by Meriton is represented by Fig. 3310. Both the inertia and the momentum of the fly-wheel are taken into consideration, as the governing forces. The contrivance is that a shaft, made wholly or partially hollow, is cut through at portions of its surface, so as to form two spiral guides or double-acting inclines. Upon this hollow shaft is fitted loosely a heavy fly-wheel having at the boss an elongated cylindrical chamber with guides cut spirally through its surface, so as to form also double-acting inclines. In the interior of the hollow shaft is a short spindle attached to a lever for working the valve. This short spindle has a pin passing through it in such a manner that the ends project and form two studs, which fit into holes cut through or in the inner surface of a ring, which ring has also forged upon its outer surface two studs. The two pins or studs within the circle of the ring pass through the spiral guides of the hollow shaft to the short spindle connected with the lever working the valve; and the two studs without the circle of the ring pass into the spiral guides in the cylindrical chamber forming part of the fly-wheel.

3311.

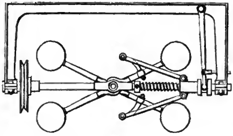


3312.



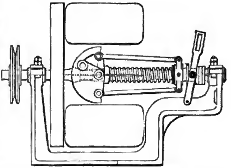
"The next example worthy of attention embracing many of the features before alluded to is Messrs. Miller and Knill's governor, illustrated by Figs. 3311, 3312. The main parts consist of a fly-wheel with an inclined face on the end of the boss; a separate portion corresponding with the inclined end of the boss is loose or slides on the shaft, and is connected to the lever in communication with the throttle-valve. The action of the component parts is as follows:—On an increased motion being communicated to the shaft by the pulley from the main cranked or engine shaft, the sliding boss closes the throttle-valve; should the speed of the engine decrease, the spring attached to the lever causes the sliding boss to move in a reverse direction, and thus the throttle-valve is opened. It may be added, in passing, that the fly-wheel, although loose on the shaft, is prevented from making more than half a revolution, by centrifugal force, by suitable stops being formed on the back of the boss, and corresponding stops on the boss of the pulley. It is presumed that the extreme simplicity of this arrangement prevents the liability of the details in question becoming disabled.

3313.



"Silver's name in connection with marine governors is well known, and the ball governor invented by him is illustrated by Fig. 3313. It consists of a spindle supporting two arms, which cross each other, and are loaded at their extremities by balls of metal. The arms are connected by links to the sliding collar, and the motion, forth and back, is communicated to the throttle-valve by the lever and rod. To ensure the return action of the sliding collar a spiral spring is wound round the spindle, and a set collar regulates the power requisite by compressing or expanding the coil.

3314.



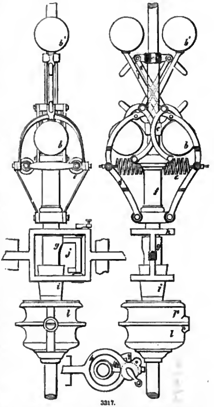
"Silver has also invented another type of governor, termed a momentum-wheel governor, and illustrated by Fig. 3314. This arrangement is a wheel with four vanes fixed on the boss of a pinion, which works loosely on the spindle and gears into two toothed sectors, these sectors being supported on a cross-head made fast to and supported by the spindle in opposite directions on the pinion; and, as they are linked by the rods to the sliding collar, a communication with the throttle-valve by the lever and rod is certain.

"When the spindle of the governor or nautical regulator is turned by the engine to which it is attached, the two toothed sectors, which are carried on the fixed cross-head, being geared into the pinion on the momentum-wheel, have the tendency to turn round on this pinion; but as they are linked to the sliding collar, they necessarily pull inwards this collar, and so compress the spiral spring, and this spring reacting on the collar, and consequently on the toothed sectors, serves to turn round the momentum-wheel, while the vanes on the momentum-wheel balance the action of this spring by the resistance the atmosphere offers to their progress through it. As the leverage action of the toothed sectors upon the momentum-wheel pinion increases, as the spring becomes distended, and *vice versâ*, it will be seen that the reaction of the spring in propelling the momentum-wheel will at all times be uniform, and as much only is required as will carry round the momentum-wheel with its vanes at its proper speed, and overcome the friction of working the throttle-valve and throttle-valve connections. When the momentum-wheel is in motion, it will rotate with the engine to which it is attached, at a velocity proportioned to that at which it is fixed by the connecting gear; and while the engine from the usual causes may attempt to vary this velocity, it cannot affect the momentum-wheel, but leaves it free to act upon the sliding collar, and consequently upon the throttle-valve—at one time closing the throttle-valve by its action in resisting any increase of velocity, and at another time opening the throttle-valve by its action in resisting any decrease of velocity on the part of the engine. It will now be evident that the power of such a governor or regulator must be very great indeed, having for its agent a momentum-wheel which may be increased to any dimensions; and from the powerful resisting tendency of such wheel, it necessarily follows that its sensitiveness of action must also be very great, and in exact proportion to the tendency of the engine to vary its speed; and the engine itself being the direct prime mover of the throttle-valve, it also follows that the inert power of the momentum-wheel increases its resistance exactly in proportion to the rapidity with which the engine varies its speed."

Farcot's Marine-engine Governor, Figs. 3315 to 3317.—This governor has four balls, *b b*, $b^1 b^1$, these being attached to arms $d\, d^1$, and these arms being, in their turn, connected by the rods $c\, c^1$ with the sliding collar *f*. The arms carrying the balls turn on the centres *a a* and $a^1\, a^1$ respectively, and the upper pair of balls are made slightly heavier than the others, so that they not only balance the latter, but the weight of the attachments also. The balls are thus placed in equilibrium as far as their weight is concerned, and the centrifugal force generated by their rotation is resisted by the transverse springs *e*, which are furnished with means of adjustment, by means of which their tension can be varied.

The sliding collar *f* has formed in one piece with it the two cams *g* and *i*, these, of course, rising and falling on the central spindle according to the variations in the position of the governor-balls. The upper cam *g* is of the shape shown in the sectional plan, and by it the cut-off of the steam is regulated, the point of the stroke of the piston at which the cut-off occurs depending upon what part of the cam *g* is brought into contact with the tappet *s*. The tappet *s* is formed on the spindle *j*, which turns in the frame *h*, and from this frame the motion imparted by the cam *g* is transmitted to the expansion-valve. The governor-spindle makes two revolutions to each revolution of the crank-shaft, so that the cam *g* is provided with one projection only.

3315. 3316.



3317.

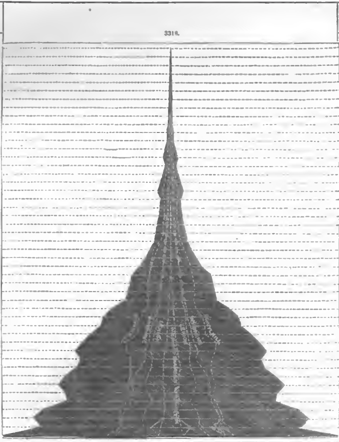
The lower cam *i* is merely a conic frustum, and its object is to govern the speed of the engine by means of the throttle-valve when, from the motion of the engine being reversed, or from other causes, the tappet *s* is thrown out of gear with the upper cam *g*. The cam *i* acts upon the tappet *t*, which, like the tappet *s*, is formed on the short spindle *j*, and it will be seen from the engraving that, by turning this spindle, either of the cams *g* or *i* can be brought into operation at pleasure, the spindle *i* being secured in the required position by the set screw *q*. In the engraving the cam *g* is shown in gear. When the cam *i* is in use, the amount of opening given to the throttle-valve of course depends upon the diameter of that portion of the cam which bears against the tappet *t*, this opening remaining constant throughout the whole revolution of the governor, so long as the balls do not alter their position. The too rapid movement of the governor-balls is prevented by a piston attached to the sliding collar *f*, and made to work in the air-cylinder *l*, this cylinder being furnished with a passage at *p*, leading from one end to the other. The sectional area of this passage, and consequently the facility with which air can be transferred from one side of the piston to the other, can be varied by means of the screw *n*, and by this means the speed with which an alteration in the positions of the balls can take place can be regulated.

See ANGULAR MOTION. BRAKE, p. 662. DETAILS OF ENGINES. ENGINES, VARIETIES OF. MARINE ENGINE. PUMPS AND PUMPING ENGINES.

GRAPHIC DIAGRAM. FR., *Diagram graphique;* GER., *Graphisches Diagram;* ITAL., *Diagramma;* SPAN., *Didgrama gráfico.*

The method of scientific analysis or investigation, in which the relations or laws involved in tabular numbers are represented to the eye by means of *diagrams*, is termed the graphic method; and, in such cases, the diagrams employed are called graphic diagrams. It is necessary here to describe the ordinary graphic diagram in which, when employed to show the daily changes of the weather, the abscissas of the curve represent the hours of the day, and the ordinates, the corresponding degrees of temperature. See R. B. Hennessey's method, pp. 406, 416.

The graphic diagram, Fig. 3318, employed by P. W. Sheafer to trace the progress of the anthracite coal trade of Pennsylvania deserves attention.



Year.	Lehigh.	Schuylkill.	Wyoming.	Shamokin, Wiconisco, and Trevorton.	Total Tons.
	tons.	tons.	tons.	tons.	
1820	365	..	..	..	365
1821	1,073	..	..	..	1,073
1822	2,240	1,480	..	..	3,720
1823	5,823	1,128	..	..	6,951
1824	9,541	1,567	..	..	11,108
1825	28,393	6,500	..	..	34,893
1826	31,280	16,767	..	..	48,047
1827	32,074	31,360	..	..	63,434
1828	30,232	47,284	..	..	77,516
1829	25,110	79,973	7,000	..	112,083
1830	41,750	89,984	43,000	..	174,734
1831	40,966	81,854	54,000	..	176,820
1832	70,000	209,271	84,600	..	363,871
1833	123,000	252,971	111,777	..	487,748
1834	106,244	226,692	43,700	..	376,636
1835	131,250	339,508	90,000	..	560,758
1836	148,211	432,045	103,861	..	684,117
1837	223,902	523,152	115,387	..	862,441
1838	213,615	433,875	78,207	..	725,697
1839	221,025	442,608	122,300	11,930	818,402
1840	225,318	452,291	148,470	15,505	864,384
1841	143,037	585,542	192,270	21,463	959,973
1842	272,546	541,504	252,599	10,000	1,108,418
1843	267,793	677,312	298,605	10,000	1,263,564
1844	371,002	840,378	365,911	13,087	1,630,850
1845	429,453	1,083,796	451,836	10,000	2,013,613
1846	517,116	1,236,682	518,389	12,572	2,344,005
1847	633,507	1,583,374	583,067	14,904	2,882,309
1848	670,321	1,652,835	685,196	19,356	3,089,238
1849	781,556	1,605,126	732,910	46,076	3,242,966
1850	690,456	1,712,007	827,823	67,684	3,358,899
1851	964,224	2,229,426	1,156,167	99,099	4,403,730
1852	1,072,136	2,450,950	1,284,600	116,342	4,633,471
1853	1,054,309	2,470,943	1,475,732	113,007	5,196,181
1854	1,207,186	2,895,208	1,602,478	234,000	6,002,334
1855	1,284,113	3,318,555	1,771,511	240,338	6,608,318
1856	1,351,970	3,258,356	1,972,581	313,444	6,927,580
1857	1,318,541	2,985,541	1,952,603	386,258	6,643,828
1858	1,380,030	2,886,449	2,186,094	370,424	6,786,369
1859	1,628,311	3,004,953	2,731,236	443,755	7,780,618
1860	1,821,674	3,270,516	2,941,817	476,116	8,412,940
1861	1,738,377	2,697,489	3,055,140	463,308	7,843,211
1862	1,351,054	2,890,898	3,145,770	481,990	7,736,899
1863	1,894,713	3,433,265	3,759,610	478,418	9,631,101
1864	2,054,669	3,642,218	3,960,836	516,792	10,184,320
1865	2,040,913	3,735,802	3,254,519	621,157	9,652,391
1866	2,179,364	4,957,180	4,736,616	830,722	12,703,882

GRATE. Fr., *Grille*; Ger., *Rost*; Ital., *Grata*; Span., *Reja*.

See Boiler.

GRAVING DOCK. Fr., *Forme de radoub*; Ger., *Trockendock*; Ital., *Bacino a secco*; Span., *Astillero*.

See Dock.

GRAVITY. Fr., *Gravité*; Ger., *Schwerkraft*; Ital., *Gravità*; Span., *Gravedad*.

Centre of Gravity.—The centre of gravity is the centre of the parallel forces due to weight. The weight of each molecule of a solid body is a vertical force acting in a downward direction. The resultant of these forces is the total weight of the body; and the centre of the parallel forces takes the name of *centre of gravity*. As a matter of fact, the common direction of the forces cannot be made to vary here; but we may, which amounts to the same thing, vary the position of the body with respect to the vertical; and the centre of gravity is the point through which the resultant of the weight of all the molecules constantly passes, whatever the position of the body may be. If the centre of gravity is one of the points in a solid body, we may conceive the weight of all the molecules replaced by a single vertical force equal to their sum and applied to the centre of gravity. But if the centre of gravity is situate outside of the body, we can conceive this substitution only by supposing the point to be invariably fixed to the system of bodies, a supposition which is made use of for the purpose of simplifying demonstrations, data, or formulæ, but to which no idea of reality can be attached. It is for this same purpose of simplifying enunciations and formulæ that we sometimes extend the notion of a centre of gravity to a system which is not solid. There exists in this case no force capable of producing by itself the effect of the weight of the various molecules which make up the system; but it is often convenient to introduce into calculations the resultant which these forces would have if the system were to become instantaneously solid, and consequently to consider the point through which the resultant would constantly pass if the system, without changing its form, changed its position with respect to the vertical, in other words, the centre of gravity of this system. In the remarks which follow we shall assume that the body in question is solid.

Bodies are, in reality, composed of molecules separated from each other; but, in seeking the centre of gravity, we consider them as formed of a continuous matter. The effect of this mode of viewing the subject is merely to misplace, by qualities infinitely small, the points of application of the vertical forces considered, an error which in no way affects the result.

I. If $p, p', p'' \ldots$ &c., denote the weight of the elements of the volume of a body, $x, y, z, x', y', z', x'', y'', z''$, &c., their co-ordinates with respect to three rectangular axes, P the total weight of the system, and X, Y, Z, the co-ordinates of the centre of gravity, we have, by taking the moments successively with respect to the three co-ordinate planes,

$$
\begin{aligned}
\mathrm{P\,X} &= p\,x + p'x' + p''x'' + \ldots = \Sigma\,p\,x,\\
\mathrm{P\,Y} &= p\,y + p'y' + p''y'' + \ldots = \Sigma\,p\,y,\\
\mathrm{P\,Z} &= p\,z + p'z' + p''z'' + \ldots = \Sigma\,p\,z,
\end{aligned}
$$

whence we deduce

$$
\mathrm{X} = \frac{\Sigma\,p\,x}{\mathrm{P}}, \qquad \mathrm{Y} = \frac{\Sigma\,p\,y}{\mathrm{P}}, \qquad \mathrm{Z} = \frac{\Sigma\,p\,z}{\mathrm{P}}, \qquad [1]
$$

formulæ which determine the centre of gravity when we know the total weight of the system, and know also how to calculate the sums which appear as the numerators of these fractions.

II. When the body under consideration is *homogeneous*, that is, when its parts, however small we may suppose them, have a weight proportional to their volume, the position of the centre of gravity in the body becomes independent of the nature of this body, and its discovery is merely a matter of geometry. If we call the volumes of the various elements of the body v, v', v'', &c., the total volume V, and the weight of the unit of matter of which its body is composed Π, we shall have $p = \Pi\,v$, $p' = \Pi\,v'$, $p'' = \Pi\,v'' \ldots$, $\mathrm{P} = \Pi\,\mathrm{V}$, and the formulæ [1] will become, by cancelling in the numerators and the denominators the common factor Π,

$$
\mathrm{X} = \frac{\Sigma\,v\,x}{\mathrm{V}}, \qquad \mathrm{Y} = \frac{\Sigma\,v\,y}{\mathrm{V}}, \qquad \mathrm{Z} = \frac{\Sigma\,v\,z}{\mathrm{V}}, \qquad [2]
$$

formulæ which no longer depend upon the nature of the body, but only upon its geometrical form.

If one of the dimensions of the body were infinitely small with respect to the other two, so that the body was reduced to a surface, the quantities v, v', v'', &c., would denote the elements of this surface, and V its total area. If two dimensions were infinitely small with respect to the third, so that the body was reduced to a line, v, v', v'', &c., would represent the elements of this line, and V its total length.

The formulæ [2] would still hold if v, v', v'', &c., instead of representing the infinitely small elements of the volume, area, or length, expressed by V, represented the finite parts of this volume, area, or length, provided that x, y, z, were then the co-ordinates of the centre of gravity of v; x', y', z', the co-ordinates of the centre of gravity of v', and so on: for the weight of each part may be considered as a vertical force applied to its centre of gravity. Consequently, the moment of the total weight is equal to the sum of the moments of the partial weights; and in the case of homogeneous bodies, *the moment of the total volume is equal to the sum of the moments of the partial volumes*, if by the moment of a volume with respect to a plane, we understand the product of this volume by the distance from its centre of gravity to this plane. Applying this theorem successively to the three co-ordinate planes, and dividing by the total volume V, we fall again upon the equations [2].

III. To simplify the labour of finding the centre of gravity in homogeneous bodies, recourse may be had to the following propositions;—

1. *If the body can be decomposed into a number of parts having their centres of gravity in the same plane, or on the same straight line, the centre of gravity of the whole body will likewise be in this same plane and upon this same straight line.* For we may suppose the weight of each part applied to the centre of gravity of this part; we have then to compose a system of forces parallel and in the same direction, whose points of application are situate, by the hypothesis, in the same plane or on the same straight line. But according to the construction which determines the centre of parallel forces, this point will itself be situate in this plane or on this straight line; and this point is the centre of gravity of the whole body.

2. *If the body has a plane of symmetry, its centre of gravity is in this plane.* It is evident that the centres of gravity of the two parts of the body separated by the plane of symmetry are symmetrically placed with respect to this plane. But these centres of gravity may be considered as the points of application of the weights of the two parts, that is, of two equal forces, parallel and in the same direction. The resultant of these two forces passes therefore through the middle of the straight line which joins their planes of application, and that, whatever the position of the body with respect to the vertical may be; this middle is therefore the centre of gravity of the body. It is evident, besides, that this middle is in the plane of symmetry.

3. *If the body has an axis of symmetry, its centre of gravity is upon this axis.* For an axis of symmetry is always the intersection of at least two planes of symmetry.

4. *If the body has a centre of shape, its centre of gravity is in this point.* For a centre of shape is the intersection of at least two axes of symmetry.

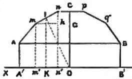
5. *We may substitute for the elements of volume, area, or length, which make up the system under consideration, other elements of volume, area, or length, proportional to them, provided they have their centres of gravity in the same points.* For the centre of the parallel forces is not changed by substituting for the given forces, other forces proportional to them and applied to the same points.

IV. We will now pass on to the consideration of the methods of finding the centre of gravity of the principal figures, and we will begin with lines.

The Straight Line.—The centre of gravity of a straight line is in its middle; for this middle is in the plane of symmetry perpendicular to the straight line.

A Regular Broken Line.—Let A $m\,n\,p\,q$ B, Fig. 3319, be a regular broken line, A B its chord, O the centre of the inscribed circle, and O C its axis of symmetry. Here the centre of gravity sought, G, will be upon O C; we have to find the distance G O. Draw through the centre X V parallel to the chord A B; and project upon this parallel line the summits of the broken line, by means of the perpendiculars A A′, $m\,m'$, $n\,n'$ . . . B B′. Let I be the middle of any part $m\,n$; join I O. Draw I K perpendicular to X Y, and $m\,h$ parallel to this line. Let x be the distance I K from the centre of gravity I of the part $m\,n$, to the straight line X Y, and X the distance O G. If we take the moments with respect to a plane drawn through X Y perpendicularly to the plane of the broken line, we shall have, from the formulæ [2], $X = \frac{\Sigma v x}{V}$ or $X = \frac{\Sigma . m n . I K}{V}$.

3319.



The similar triangles I K O and $m\,h\,n$ give $m n : I O = m h : I K$, whence $m a . I K = I O . m h$; consequently, $X = \frac{\Sigma . I O . m h}{V}$; or, as I O, the radius of the inscribed circle, is a factor common to all the terms of the numerator, and as $m' a'$ may be substituted for $m\,h$, $X = \frac{I O . \Sigma m' n'}{V}$. But $\Sigma m' n'$, or the sum of the projections of the sides or parts of the broken line upon X Y is A′ B′, which is equal to A B; and V is here the length A $m\,n\,p\,q$ B of the broken line. We may therefore write $O G = \frac{I O . A B}{A m n p q B}$, that is, *the distance from the centre of gravity of a broken line to its centre is a fourth proportional to the length of this broken line, its chord, and the radius of the inscribed circle.*

Circular Arcs.—The preceding proposition is independent of the number of parts in the broken line; it is therefore true if this number becomes infinitely great, that is, if the broken line becomes an arc of a circle calling the length of the developed arc L, its chord C, and the radius of the inscribed circle, which in this case will be confounded with the arc itself, R, we have $X = \frac{R . C}{L}$. We may therefore affirm that *the centre of gravity of an arc of a circle is upon its axis of symmetry, and its distance from the centre is a fourth proportional to the arc, its chord, and the radius.* For a half circle we should have $X = \frac{R . 2 R}{\pi R} = \frac{2}{\pi} R$.

Curves.—If the curve is plane, let $y = f(x)$ be its equation with respect to two rectangular axes traced in its plane, and let $d s$ be an element of the curve, corresponding to the co-ordinates x and y; the equations of the moments will give, calling s the developed length of the curve from the point the abscissa of which is x_0 to the point the abscissa of which is x_1,

$$s . X = \int_{x_0}^{x_1} x \, d s, \text{ and } s Y = \int_{x_0}^{x_1} y \, d s.$$

But we have $ds = dx\sqrt{1+[f'(x)]^2}$; consequently, deducing the values of X and Y, it will become

$$X = \frac{\int_{x_0}^{x_1} x\,dx\sqrt{1+[f'(x)]^2}}{\int_{x_0}^{x_1} dx\sqrt{1+[f'(x)]^2}}, \quad \text{and} \quad Y = \frac{\int_{x_0}^{x_1} f(x)\,dx\sqrt{1+[f'(x)]^2}}{\int_{x_0}^{x_1} dx\sqrt{1+[f'(x)]^2}}.$$

If the curve has a double curvature, let $x = \phi(z)$ and $y = \psi(z)$, be its equations with respect to three rectangular axes; let s be again the developed length of the curve from $z = z_0$ to $z = z_1$. We shall have by the theorem of the moments,

$$s\,X = \int_{z_0}^{z_1} x\,ds, \quad s\,Y = \int_{z_0}^{z_1} y\,ds, \quad s\,Z = \int_{z_0}^{z_1} z\,ds;$$

but here $ds = dz\sqrt{1+[\phi'(z)]^2 = [\psi'(z)]^2}$. Deducing the values of X Y, Z, we have

$$X = \frac{\int_{z_0}^{z_1} \phi(z)\,dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}}{\int_{z_0}^{z_1} dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}},$$

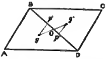
$$Y = \frac{\int_{z_0}^{z_1} \psi(z)\,dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}}{\int_{z_0}^{z_1} dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}},$$

$$Z = \frac{\int_{z_1}^{z_0} z\,dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}}{\int_{z_1}^{z_0} dz\sqrt{1+[\phi'(z)]^2+[\psi'(z)]^2}}.$$

V. We will now consider the centre of gravity of plane figures.

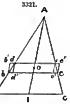
Rectangular Figures.—The centre of gravity of a rectangular figure is its centre of shape, that is, the point of intersection of its median or bisecting lines, which are axes of symmetry.

3320.



The Parallelogram.—Let A B C D, Fig. 3320, be a parallelogram. Draw the diagonal B D, which will divide it into two equal triangles. Let g and g' be the centres of gravity of these triangles; draw $g\,p$ and $g'\,p'$ perpendicular to B D, and let O be the middle of the diagonal B D. Without knowing the position of the points g and g' with respect to the two triangles to which they belong, we may admit that as these triangles are equal, their centres of gravity would coincide if the triangles were placed one upon the other. We have therefore $g\,p = g'\,p'$ and $O\,p = O\,p'$, consequently the angles $p\,O\,g$ and $p'\,O\,g'$ are equal, and $g\,O = g'\,O$. Therefore $g\,O\,g'$ is a straight line, and the point O is the middle of it. But the weights of the triangles A B D and B D C may be considered as applied to g and g'; the point of application of their resultant, that is, the centre of gravity of the parallelogram, is therefore situate in the middle of the straight line $g\,g'$, that is, in the point O, which is the middle of the diagonal B D. Thus *the centre of gravity of a parallelogram is in the middle of the diagonals*, which is also their point of intersection.

3321.



The Triangle.—Let A B C, Fig. 3321, be a triangle. Bisect B C and join A I. Draw $b\,c$ and $d\,e$ parallel to B C; and $b\,b'$, $c\,c'$, $d\,d'$, $e\,e'$ parallel to A I, which passes through the middle of $b\,c$ and $d\,e$, and also of $b'\,c'$ and $d'\,e'$, since $b'\,d = b\,d'$ and $e\,c = e'\,c$. The centre of gravity of the parallelogram $b\,b'\,c'\,c$ is therefore situate upon the straight line A I, in the middle O of the portion of this straight line included between $b\,c$ and $d\,e$. Likewise the centre of gravity of the parallelogram $d'\,d\,e'\,e$ is situate upon A I, in the middle of the portion of this straight line included between $b\,c$ and $d\,e$, that is, in the same point O. But the nearer the straight lines $b\,c$ and $d\,e$ are together, the smaller is the difference of the parallelograms $b\,b'\,c'\,c$ and $d'\,d\,e\,e'$ with respect to each other; and consequently the more they tend to be confounded with each other, and with the trapezium $b\,d\,e\,c$ included between them. Therefore, when the distance between the straight lines $b\,c$ and $d\,e$ is infinitely small, we may consider the trapezium $b\,d\,e\,c$ as confounded with one of these parallelograms, and we have consequently its centre of gravity in the same point O upon A I. It follows from this that if we conceive the triangle decomposed by lines parallel to B C into trapeziums infinitely narrow, all of these trapeziums may be considered as having their centres of gravity upon A I. Therefore, in virtue of the principle I established above, the centre of gravity of the triangle A B C is situate upon A I.

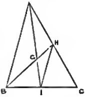
This being proved, and we might prove the same for any other bisecting line, taking another side as a base, it follows that *the centre of gravity of a triangle is in the point in which the three bisecting lines intersect each other.*

Let A I and B H, Fig. 3322, be two of these bisecting lines, and G their point of intersection. Join I H. The triangles I G H and A G B being similar, we shall have the proportion I G : A G = I H : A B. But the triangles I C H and B C A being also similar, we shall have I H : A B = I C : B C = 1 : 2, therefore, by reason of the common relation, I G : A G = I : 2, whence we deduce

$$IG : IG + AG = 1 : I + 2, \text{ or } IG : A = I : 3,$$

that is, I G is a third of A I. Therefore *the centre of gravity of a triangle is situate upon the straight line which joins the summit to the middle of the base, and one-third of this line distant from the base.*

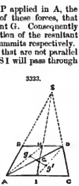
3322.



The centre of gravity of a triangle possesses a property which is worthy of being known. Suppose applied to the three summits, three equal forces, parallel and in the same direction, the common intensity of which we will represent by P. Required the point in the triangle through which the resultant of the three forces passes. The law for the composition of forces will give us, first, for the two forces P applied in B and C, a force 2 P applied in the middle I of B C; and for this force 2 P applied in I and the force P applied in A, the resultant is found by dividing the distance A I in the inverse proportion of these forces, that is, in the inverse proportion of the numbers 2 and 1, which will give the point G. Consequently the centre of gravity of a triangle may be regarded as the point of application of the resultant of three equal forces, parallel and in the same direction applied to the three summits respectively.

Trapezium.—Let A B D C, Fig. 3323, be a trapezium. Produce the sides that are not parallel till they meet in S; join this point to the middle I of the base A C. The line S I will pass through the middle H of the base B D. It may be shown from the principles employed above that the centre of gravity of the trapezium must be upon the straight line I H. But if we draw the diagonal A D, and determine the centres of gravity g and g' of the two triangles A B D and A D C into which the trapezium has been resolved, the centre of gravity of the trapezium must also be upon the straight line $g g'$, since the weight of the trapezium is the resultant of the weights of the two triangles. The centre of gravity required is therefore in G the point of intersection of the straight lines I H and $g g'$.

3323.



It may be remarked that the line $g g'$ is divided at the point G in the inverse proportion of the weights, or of the surfaces of the two triangles. But these triangles are equal in height; the line $g g'$ is therefore divided in the inverse proportion of the bases A D and B C. It may sometimes be required to know the proportion of the segments G I and G H of the bisecting line I H. To ascertain this, proceed as follows. The proportion required is the same as the proportion of the distances from the point G to the two bases. Let x and y be these distances, and $h = x + y$ the height of the trapezium. Denote A C by B and B D by b. Apply to the weight of the trapezium and to the weights of the two triangles B A D and A C D the theorem of the moments, taking first as the plane of the moments a plane upon the line A C perpendicular to the plane of the trapezium. The distances from the centres of gravity g and g' to the plane of the moments, or, which amounts to the same thing, to A C, will be $\frac{1}{3} h$ for the triangle D A C and $\frac{2}{3} h$ for the triangle B A D. We shall have therefore, substituting for the weights the areas which correspond to them,

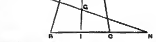
$$ABDC \, . \, x = DAC \cdot \frac{I}{3} h + BAD \cdot \frac{2}{3} h, \quad \text{or} \quad ABDC \, . \, x = \frac{I}{6} h^2 (B + 2b).$$

Taking the moments with respect to a plane upon B D perpendicular to the plane of the trapezium, and observing that the distance from the points g and g' to B D is $\frac{1}{3} h$ for the first, and $\frac{2}{3} h$ for the second, we shall have likewise,

$$ABDC \, . \, y = DAC \, . \, \frac{2}{3} h + BAD \, . \, \frac{I}{3} h, \quad \text{or} \; ABDC \, . \, y = \frac{1}{6} h^2 (2B + b).$$

Dividing member by member the two equations thus obtained, we find $\frac{x}{y}$ or $\frac{GI}{GH} = \frac{B + 2b}{2B + b}$.

3324.

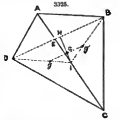


This formula leads us to the following construction:—Produce D A, Fig. 3324, by a quantity A M equal to B C; produce B C in the contrary direction by a quantity C N equal to A D; join M N, which will cut I H in the centre of gravity G. Accordingly we have $\frac{GI}{GH} = \frac{IN}{MH} = \frac{\frac{1}{2}B + b}{B + \frac{1}{2}b} = \frac{B + 2b}{2B + b}$, as the formula requires.

If the bases B and b differed infinitely little from each other, B + 2 b would be sensibly equal to $2B + b$, and we should have sensibly $GI = GH$, that is, the point G would be in the middle of the bisecting line I H. This is what happens in the case of the elementary trapeziums considered in the demonstration relative to the centre of gravity of the triangle.

Any Quadrilateral.—Let A B C D, Fig. 3325, be a quadrilateral. Draw the two diagonals, which will intersect each other in the point E. Let I be the middle of the diagonal A C; join D I and B I. Take upon these straight lines the points g and g' at a distance of one-third of their length from the point I; these points will be the centres of gravity of the triangles A D C and A B C. Consequently, if we join them by a straight line $g g'$, the centre of gravity of the quadrilateral will be upon this line, and will divide it in inverse proportion to the surfaces of the triangles. But these triangles, which have the same base A C, are to each other as their heights, or as the lines D E and B E which are proportional to them. We ought therefore to have, if G is the point sought, $Gg : Gg' = BE : DE$.

3325.



To fulfil this condition, it is sufficient to take B H, equal to D E, and to join the point H to the point I by a straight line cutting $g g'$ in the required point G. For we shall have

$$Gg : Gg' = DH : BH = BE : DE.$$

It may be remarked that we have also $IG : IH = Ig : ID$, and that consequently I G is a third of I H. Hence the following construction;—Draw the two diagonals A C and B D meeting each other in E; take upon one of them the length B H equal to the segment D E; join the point H thus found to the middle I of the other diagonal, and take upon I H a third from the point I. The point G thus found will be the centre of gravity of the quadrilateral.

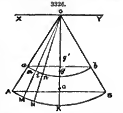
The Polygon.—To find the centre of gravity of any polygon, divide it into triangles; determine the area and the centre of gravity of each one of them, and apply the construction, which gives *the centre of parallel forces.*

A Regular Polygon.—The centre of gravity of a regular polygon is its centre of shape.

The Circle.—The centre of gravity of a circle is its centre.

The Circular Sector.—Let A O B, Fig. 3326, be a circular sector. Conceive the arc A B which forms the base divided into a large number of equal parts, and radii drawn to all the points of division. The surface of the sector is then divided into a large number of equal elementary sectors, as M O N; and as the arcs, such as M N, are supposed to be very small, these sectors may be considered as rectilinear triangles. From the point O as a centre with a radius equal to ⅔ of the radius O A, describe the arc $a b$; this arc will be divided by the radii, such as O M and O N, drawn to the points of division of the arc A B, into the same number of equal parts, as $m n$; which may be considered as straight lines parallel to the corresponding elements of the arc A B. The centre of gravity of the triangle M O N is in the middle i of the straight line $m n$ drawn parallel to the base at ⅔ of the distance between the summit and this base; for this point i is on the bisecting line that would be drawn from the point O, and at a distance from the summit of ⅔ of this line. But the point i is also the middle of $m n$; and the same may be said of the other elementary triangles. In virtue of the principle V established above, we may therefore substitute for the superficial elements, as M O N, the linear elements as $m n$, since they are proportional to them, and have their centres of gravity in the same points. It follows from this that *the centre of gravity of the circular sector is the same as that of the arc $a b$ described from the centre O with ⅔ of the radius.* This centre of gravity is therefore upon the line which bisects the angle A O B, at a distance ρ from the centre indicated by the expression $\rho = \frac{Oa \,.\, ab}{amb}$. But $Oa = \frac{2}{3} OA$, $ab = \frac{2}{3} AB$, $amb = \frac{2}{3} AMB$; we may therefore write $\rho = \frac{2}{3} \cdot \frac{OA \,.\, AB}{AMB}$, that is, *to find the centre of gravity of a circular sector, find the centre of gravity of the arc forming the base, join this point to the centre, and take two-thirds of the joining line, reckoning from the centre.*

3326.



For a semicircle with a radius R, we should have $\rho = \frac{2}{3} \cdot \frac{R \,.\, 2R}{\pi R}$ or $\rho = \frac{4}{3\pi} \,.\, R$.

Circular Trapezium.—Let A B b a, Fig. 3326, be a circular trapezium. Denote the radii O A and O a by R and r, and the angle A O B by α. The centre of gravity sought G will be upon the bisecting line O K: for the centre of gravity g of the sector a O b and the centre of gravity g' of the sector A O B are upon this line, and the weight of the sector A O B is the resultant of the weight of the sector a O b and that of the trapezium A B b a. Through the point O draw a plane perpendicular to O K; and let X Y represent this plane upon the plane of the trapezium; taking the moments with respect to this plane, we have $AOB \,.\, Og = aOb \,.\, Og' + ABba \,.\, OG$, whence

$$OG = \frac{AOB \,.\, Og - aOb \,.\, Og'}{AOB - aOb}.$$

But, $AOB = \frac{1}{2} R^2 \alpha$, $aOb = \frac{1}{2} r^2 \alpha$, $Og = \frac{2}{3} \cdot \frac{R \,.\, 2R \sin. \frac{1}{2}\alpha}{R\alpha}$ and $Og' = \frac{2}{3} \cdot \frac{r \,.\, 2r \sin. \frac{1}{2}\alpha}{r\alpha}$;

substituting and reducing, we get

$$OG = \frac{2}{3} \cdot \frac{R^3 - r^3}{R^2 - r^2} \cdot \frac{\sin. \frac{1}{2} a}{\frac{1}{2} a} \text{ or } OG = \frac{2}{3} \cdot \frac{R^2 + Rr + r^2}{R + r} \cdot \frac{\sin. \frac{1}{2} a}{\frac{1}{2} a}.$$

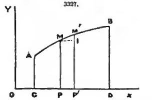
Denoting half the sum of the radii R and r by ρ and half their difference by e, which gives $R = \rho + e$ and $r = \rho - e$, we may put the above expression under the form

$$OG = \left(\rho + \frac{e^2}{3\rho}\right) \cdot \frac{\sin. \frac{1}{2} a}{\frac{1}{2} a},$$

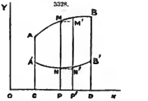
which is often convenient for use, especially in finding the centre of gravity of the voussoirs of a semicircular or segmental vault.

A Figure bounded by a Curve.—We will consider, in the first place, a trapezium A B D C, Fig. 3327, bounded by any curve A B, the equation of which is given by the axis of the x's and by two ordinates, A C and B D, corresponding to the abscissæ a and b. This trapezium may be considered as composed of an infinity of rectangles, as M P P′ I, having as their height the ordinate M P or y, and as a base the infinitely small increase P P′ from the abscissa, or dx. The distance of the centre of gravity of this rectangle from the axis of the y's is equal to $x + \frac{1}{2} dx$, and its distance from the axis of the x's is $\frac{1}{2} y$; we shall have therefore, calling the area of trapezium A B D C A, and neglecting $\frac{1}{2} dx$ before x, $A . X = \int_a^b x y \, dx$, and $A . Y = \int_a^b \frac{1}{2} y^2 . dx$, besides $A = \int_a^b y \, dx$. Putting for y its value in x and integrating, we have the co-ordinates X and Y of the centre of gravity sought.

3327.



3328.



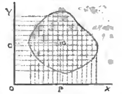
Suppose, in the second place, we have to consider the area included between two curves A B and A′ B′, Fig. 3328, the equations of which are given, and the ordinates corresponding to the abscissæ O B = a, and O D = b. We shall consider the proposed area as made up of an infinite number of rectangles, as M N N′ M′, having as a base the infinitely small increase P P′, or dx, from the abscissa, and for height the difference M N between the ordinates M P = y and N P = y' of the two curves corresponding to the same abscissa x. The distance of the centre of gravity of this rectangle from the axis of the y's will be again $x + \frac{1}{2} dx$, or simply x; and its distance from the axis of the x's will be $\frac{1}{2}$ (M P + N P) or $\frac{1}{2} (y + y')$. We shall have therefore, calling the area A B′ B A′ A, $A . X = \int_a^b x (y - y') \, dx$, and $A . Y = \int_a^b \frac{1}{2} (y + y') . (y - y') \, dx$; besides

$$A = \int_a^b (y - y') \, dx.$$

Putting for y and y' their values in x and integrating, we obtain the co-ordinates X and Y. This calculation is evidently applicable to the case in which the curve A′ B′ is a second branch of the curve A B, and consequently to the determination of the centre of gravity of the area included under a closed curve the equation of which is given.

If we have to consider an area enclosed by an irregular curve, or one whose equation we do not possess, we may make use of the following method;—Draw lines parallel to the axes, Fig. 3329, at equal distances apart, these distances being small enough to allow us to consider the portions of the contour included between two consecutive parallels as sensibly rectilinear. The whole figure is thus divided into squares, rectangular trapeziums and rectangular triangles, figures whose areas and centres of gravity we are able to determine. Taking the moments of these partial areas with respect to the two axes and summing, we get the moments of the total area; and as this total area is the sum of the partial areas, by dividing the moments found by this total area, we obtain the co-ordinates of the centre of gravity with an approximation that increases as the space between the parallels decreases.

3329.



VI. We have now to determine the centre of gravity of curved surfaces.

Surfaces of Revolution.—Let O X, Fig. 3327, be the axis of revolution, and A B the generating line, or generatrix, whose equation is supposed to be given; and let O C $= a$ and O D $= b$ be the abscissæ of the planes perpendicular to the axis O X serving as limits to the surface. Divide this surface by planes M P, M P′, perpendicular to the axis of revolution, into infinitely small zones, which may be considered as surfaces of frusta of cones. Let x and y be the co-ordinates of the point M, and s the arc A M of the generatrix. We shall have as the expression of the surface of the frustum generated by the element M M′ or $d\,s$, $\frac{1}{2}\left(2\pi y + 2\pi(y + d y)\right) d s$ or $2\pi y\, d s$, by neglecting the infinitely small $d y$ before the finite quantity y.

The centre of gravity of this elementary zone is situate upon the axis of revolution between the points P and P′, and consequently its distance from the point O is expressed by $x + \epsilon\, d x$, ϵ denoting a fraction. The centre of gravity of the whole surface is likewise situate upon the axis, and, calling its distance from the point O, X, and the area of the surface S, we have, by the theorem of the moments, $\mathrm{S}\,.\,\mathrm{X} = \int_a^b 2\pi y\,.\,d s\,(x + \epsilon\, d x) = 2\pi \int_a^b x\, y\, d s$, by neglecting $\epsilon\, d x$ before x. We have besides, $\mathrm{S} = 2\pi \int_a^b y\, d s$. Therefore, putting for $d s$ its value $d x \sqrt{1 + y'^2}$, replacing the ordinate y and its derivative y' by their values in x and integrating, we obtain the distance X.

We should thus find that *the centre of gravity of the surface of a* CONE OF REVOLUTION *is situate upon its axis, at a distance of one-third of its length from the base.* We should see in like manner that the centre of gravity of the surface of a frustum of a cone is situate upon its axis of revolution, and that it divides it into two portions x and y, the expression of whose ratio is $\frac{x}{y} = \frac{2\,\mathrm{R} + r}{\mathrm{R} + 2\,r}$, where R denotes the radius of the larger base and r the radius of the smaller.

Spherical Zone.—In the case of a spherical zone we have $y = \sqrt{\mathrm{R}^2 - x^2}$, whence $y' = \frac{x}{\sqrt{\mathrm{R}^2 - x^2}}$, and $\sqrt{1 + y'^2} = \frac{\mathrm{R}}{\sqrt{\mathrm{R}^2 - x^2}}$. It follows from this that $y\, d s = \mathrm{R}\, d x$, and

$$\mathrm{S} = 2\pi \int_a^b \mathrm{R}\, d x = 2\pi \mathrm{R}\,(b - a).$$

We have further, $\mathrm{S\,X} = 2\pi \int_a^b \mathrm{R}\, x\, d y = 2\pi \mathrm{R}\,\frac{(b^2 - a^2)}{2}$; consequently $\mathrm{X} = \frac{1}{2}(b + a)$.

This value is the abscissa of the middle of the axis; consequently *the centre of gravity of a zone is the middle of its axis.*

Any Surface whatever.—Let $z = \phi(x, y)$ the equation of the surface, and S the area included between the limits assigned, a and a' for x, b and b' for y. The expression of the element of surface is $d\mathrm{S} = d x\, d y \sqrt{1 + [\phi'_x(x, y)]^2 + [\phi'_y(x, y)]^2}$, and the whole surface is expressed by

$$\mathrm{S} = \int_a^{a'} \int_b^{b'} d x\, d y \sqrt{1 + [\phi'_x(x, y)]^2 + [\phi'_y(x, y)]^2}.$$

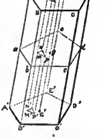
We have further, by the theorem of the moments,

$$\mathrm{S\,X} = \iint x\, d\mathrm{S}, \qquad \mathrm{S\,Y} = \iint y\, d\mathrm{S}, \qquad \mathrm{S\,Z} = \iint z\, d\mathrm{S}.$$

Substituting for $d\mathrm{S}$ and z their values in x and y, and integrating between the limits indicated, we obtain the values of the co-ordinates X, Y, Z, of the centre of gravity required.

VII. It remains for us now to consider the centre of gravity of volumes.

3330.



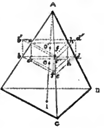
The Prism.—Let A B C D E A′ B′ C′ D′ E′, Fig. 3330, be any prism. We may conceive this prism divided, by planes parallel to the bases, into equal and infinitely thin sections. These sections will have their centres of gravity similarly placed, since they are equal to each other. All their centres of gravity will therefore be upon the same straight line G G′ parallel to the lateral edges; consequently the centre of gravity of the whole prism will be upon this line. Again, it will be in the middle g of this line; for the weight of these sections will be equal and parallel forces applied in equidistant points of G G′, and consequently, as we may consider the line G G′ loaded with weights uniformly distributed throughout its length, the point of application of their resultant is in the middle of this length. The centre of gravity g of the prism is therefore situate in the section $a\,b\,c\,d\,e$ parallel to the bases and equally distant from them. It is also the centre of gravity of this section. Suppose the whole prism decomposed into infinitely small triangular prisms, as M N P M′ N′ P′, having their edges parallel to those of the given prism; and let $m\,n\,p$ be the section of one of these elementary prisms by the plane $a\,b\,c\,d\,e$. Conceive a plane P perpendicular to the bases of the prism, and take the moments of the elementary prisms and of the whole prism with respect to this plane. Denote the height of the prism by h, the area $m\,n\,p$ by ω, the distance of the centre of gravity of the elementary prism from the plane P by x, the distance of the centre of gravity of the triangle $m\,n\,p$ from the same plane by x'; the distance of the centre of gravity of the whole prism by X, and that of the centre of gravity of the polygon $a\,b\,c\,d\,e$ by X′. It may be remarked that x and x' can differ only by an infinitely small quantity ϵ, since the centres of gravity of the elementary prism and of the mean section are both situate in the infinitely small triangle $m\,n\,p$, say $x' = x + \epsilon$. Representing the area of the polygon $a\,b\,c\,d\,e$ by Ω, we have $h\,\Omega\,.\,X = \Sigma\,h\,\omega\,.\,x$, whence $\Omega\,X = \Sigma\,\omega\,x$, and $\Omega\,X' = \Sigma\,\omega\,(x + \epsilon)$, or, neglecting the infinitely small ϵ before the finite quantity x, $\Omega\,X' = \Sigma\,\omega\,x = \Omega\,X$; whence $X' = X$.

Thus the centre of gravity of the given prism and that of the section $a\,b\,c\,d\,e$ are at the same distance from the plane P; and as this plane is any plane perpendicular to the bases, it follows that the two centres of gravity coincide. Consequently *the centre of gravity of a prism is that of the section parallel to the bases and equally distant from those bases.*

The same demonstration applies to right and oblique cylinders.

The Tetrahedron.—A demonstration analogous to the above may be applied to the tetrahedron, and generally to the pyramid and the cone. But on account of the importance which the research for the centre of gravity of the tetrahedron possesses, it will be well to apply to it a special geometrical method. Let A B C D, Fig. 3331, be the given tetrahedron. Join the point A to the centre of gravity I of the opposite face. Draw the planes $b\,c\,d$, $e\,f\,h$, parallel to B C D; and the straight lines $b\,b'$, $c\,c'$, $d\,d'$, $e\,e'$, $f\,f'$, $h\,h'$, parallel to A I, and terminating in these planes; join $b'\,c'$, $c'\,d'$, $b'\,d'$, and $e'\,f'$, $f'\,h'$, $e'\,h'$.

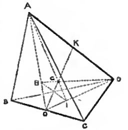
3331.



The straight line A I being drawn to the centre of gravity of the base B C D, passes through the centres of gravity o and o' of the sections $b\,c\,d$ and $e\,f\,h$; for the point A is their common centre of similitude. The triangular prisms $b\,c\,d$, $b'\,c'\,d'$, $e\,f\,h$, $e'\,f'\,h'$, the lateral edges of which are parallel to A I, have therefore both of them their centre of gravity in the middle of $o\,o'$. But the nearer the sections $b\,c\,d$, $e\,f\,h$, are together, the more will the truncated pyramid $b\,c\,d\,e\,f\,h$, included between the two prisms, tend to confound itself with each of them. Therefore, when the distance $o\,o'$ is infinitely small, we may consider the truncated pyramid as confounded with one or the other of these prisms, and that consequently it has its centre of gravity in the same point upon the line A I. It follows from this that if we conceive the tetrahedron decomposed, by planes parallel to B C D, into infinitely thin truncated pyramids, all these truncated pyramids may be considered as having their centres of gravity upon the line A I. Therefore, in virtue of principle I, the centre of gravity of the tetrahedron A B C D is situate upon the same line A I. As the same result would be arrived at if we took another face as a base, it follows that *the centre of gravity of a tetrahedron is in the point of intersection of the straight lines drawn from each summit to the centre of gravity of the opposite face.*

This being established, let O, Fig. 3332, be the middle of the edge B C; draw A O and D O, take O H equal to a third of A O, and O I equal to a third of O D. The points H and I will be respectively the centres of gravity of the forces A B C and B C D. Draw A I and D H. These straight lines which are both in the plane A O D, will meet in a point G, which will be the centre of gravity of the tetrahedron. But, if we draw I H, the similar triangles I G H and A G D will give the proportion I G : G A = I H : A D; but the similar triangles I O H and A O D also give I H : A D = O I : O D = 1 : 3; therefore, on account of the common proportion, I G : G A = 1 : 3, whence I G : I G + G A = 1 : 1 + 3, or I G : I A = 1 : 4, that is, I G is a fourth of A I. Thus *the centre of gravity of a tetrahedron is situate upon the straight line which joins the summit to the centre of gravity of the base, at a distance of one-fourth of this line from the base.*

3332.



It may be remarked that if through the point G we draw a plane parallel to the base B C D of the tetrahedron, this point will be the centre of gravity of the section determined by this plane; so that *the centre of gravity of a tetrahedron is that of the section parallel to its base, at a quarter of the distance between this base and the opposite summit.*

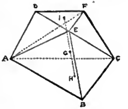
Suppose the points A, B, C, D, to be the points of application of four equal and parallel forces the common intensity of which we will represent by P. To compose these four forces, we may first compose the two forces P applied to the points B and C, which will give a force 2 P applied to the middle O of B C. We shall have, further, to compose this force 2 P applied in O with the force P applied in D; to do this we must divide the distance O D in the inverse ratio of these forces, that is, in the inverse ratio of the numbers 2 and 1, which will give the point I, the centre of gravity of the base B C D. Lastly, we shall have to compose the force 3 P applied in I with the force P applied in A; to do this we must divide A I in the inverse ratio of the numbers 3 and 1, which will give exactly the point G.

Consequently *the centre of gravity of a tetrahedron is the point of application of the resultant of four equal forces, parallel and in the same direction applied to the four summits respectively.*

The four forces P may be composed in another way. We may first compose the forces P applied in B and C into a single force 2 P applied in the middle O of B C. We may then compose the two other forces P applied in A and D into a single force 2 P applied in the middle K of A D. It will remain to compose the force 2 P applied in O with the force 2 P applied in K, which will give a force 4 P applied in the middle G of the straight line O K. The point G found in this way must evidently be the same as that which has been found by another method of composition. Therefore *the centre of gravity of a tetrahedron is in the middle of the straight line which joins the middles of two opposite edges.* As there are three analogous right lines joining the middles of two opposite edges, it follows from what we have just said that these three right lines cut each other in the middle; which is indeed a known theorem in geometry.

Truncated Tetrahedron.—Let A B C D E F, Fig. 3333, be the given frustum. It may be demonstrated, as in the case of the tetrahedron, that the centre of gravity must be upon the straight line I H which joins the centres of gravity of the two bases. Let G be this point; it remains for us to determine the ratio of the lengths G I and G H, or, which amounts to the same thing, the ratio of the distances from the point G to the planes of the two bases. Let x and y be these distances; then $x + y = h$ the height of the frustum. Denote the base A B C by B, and the base D E F by b. Decompose the frustum into three pyramids by the planes A E C and A E F, as would be done in finding its volume; and take successively the moments with respect to the two bases, noting that the distances from the centres of gravity of these partial pyramids to the bases D E F and A B C are respectively $\frac{1}{4}h$ and $\frac{3}{4}h$ for the pyramid A D E F, $\frac{3}{4}h$ and $\frac{1}{4}h$ for the pyramid E A B C, and $\frac{1}{2}h$ and $\frac{1}{2}h$ for the pyramid E A F C, as its centre of gravity is in the middle of the straight line which would join the middles of the opposite edges E F and A C. We shall have therefore, by first taking the moments with respect to the base D E F,

3333.



$$\mathrm{ABCDEF}\,.\,x = \mathrm{ADEF}\,.\,\frac{1}{4}h + \mathrm{EABC}\,.\,\frac{3}{4}h + \mathrm{EFAC}\,.\,\frac{1}{2}h,$$

$$\text{or}\qquad \mathrm{ABCDEF}\,.\,x = \frac{1}{12}h^2\left(b + 3\,\mathrm{B} + 2\sqrt{\mathrm{B}b}\right).$$

Then taking the moments with respect to the base A B C, we shall have in like manner

$$\mathrm{ABCDEF}\,.\,y = \mathrm{ADEF}\,.\,\frac{3}{4}h + \mathrm{EABC}\,.\,\frac{1}{4}h + \mathrm{EFAC}\,.\,\frac{1}{2}h,$$

$$\text{or}\qquad \mathrm{ABCDEF}\,.\,y = \frac{1}{12}h^2\left(3b + \mathrm{B} + 2\sqrt{\mathrm{B}b}\right).$$

Dividing the two equalities member by member, and simplifying, we find

$$\frac{x}{y} = \frac{\mathrm{GI}}{\mathrm{HG}} = \frac{b + 3\,\mathrm{B} + 2\sqrt{\mathrm{B}b}}{3b + \mathrm{B} + 2\sqrt{\mathrm{B}b}}. \qquad [\mathrm{A}]$$

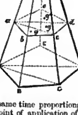
The bases B and b may be replaced by the squares of their homologous edges, since they are proportional to them; calling these edges A and a, we get

$$\frac{x}{y} = \frac{\mathrm{GI}}{\mathrm{HG}} = \frac{a^2 + 3\,\mathrm{A}^2 + 2\,\mathrm{A}a}{3\,a^2 + \mathrm{A}^2 + 2\,\mathrm{A}a}.$$

It may be remarked that when the two bases are infinitely near, they differ infinitely little from each other, and that G I is then sensibly equal to G H, that is, the centre of gravity is sensibly in the middle of the straight line which joins the centres of gravity of the two bases. This was what occurred in the case of the elementary sections under consideration when we were seeking the centre of gravity of the tetrahedron.

Any Pyramid.—Let S A B C D E, Fig. 3334, be a pyramid with any base. Decompose it into tetrahedrons by the diagonal planes A S C and A S D. At a distance from the base equal to a quarter of the height of the pyramid, draw a plane $abcde$ parallel to this base. This plane will contain the centres of gravity g, g', g'', of the partial tetrahedrons, and consequently the centre of gravity of the whole pyramid (Principle I). But the tetrahedrons S A B C, S A C D, S A D E, having the same height, are to each other as their bases, or as the triangles abc, acd, ade, proportional to these bases. Therefore, if we suppose applied to the points g, g', g'', weights equal to those of the corresponding tetrahedrons, these weights would be at the same time proportional to the areas of the triangles abc, acd, ade. Hence it follows that the point of application of the resultant of these weights is no other than the centre of gravity of the polygon $abcde$. But it

3334.



may be easily seen by simple similitudes of triangles, that the straight line which joins the summit S to the centre of gravity of the base A B C D E of the pyramid, passes through the centres of gravity of all the sections, as *a b c d e*, parallel to this base. Therefore *the centre of gravity of any pyramid is upon the straight line which joins the summit to the centre of gravity of the base, at a distance of one-fourth of this line from the base.*

This theorem extends to a cone, whether right or oblique, and with any base, since such a body is a pyramid whose base is a polygon with an infinite number of infinitely small sides.

Truncated Pyramid.—If the frustum of the pyramid be decomposed into frusta of tetrahedrons, their upper bases will be proportional to the lower, and generally to the sections made by the same plane parallel to the bases. Hence it follows that the ratio of the distances from their centres of gravity to the two bases will be the same for each of them, and that consequently their centres of gravity will be in the same plane parallel to the bases, and determined by the formula [A] given above for the frustum of tetrahedron. The centre of gravity of the whole frustum of the pyramid will therefore be also in this plane. Again, the partial truncated tetrahedrons having the same height, and proportional bases, are to each other as these bases, or as the sections made by the plane containing the centres of gravity of the partial tetrahedrons. Therefore *the centre of gravity of a frustum of the pyramid is upon the straight line which joins the centres of gravity of the two bases, and it divides this line in the proportion expressed by the formula* [A] *relative to the tetrahedron*, the letters B and b denoting in this case the bases of the frustum of the pyramid.

This proposition extends to the frustum of the cone; and the bases of B and b being in this case proportional to the squares of their radii R and r, we have, still denoting by x and y the segments determined by the centre of gravity sought upon the straight line which joins the centres of gravity of the two bases, $\frac{x}{y} = \frac{r^2 + 3\,\mathrm{R}^2 + 2\,\mathrm{R}\,r}{3\,r^2 + \mathrm{R}^2 + 2\,\mathrm{R}\,r}$.

The Sphere.—The centre of gravity of a sphere is its centre of shape.

A Spherical Sector.—We may conceive the sector divided up into elementary pyramids, all of them having their summits in the centre of the sphere. The centre of gravity of each of them will be upon the radius drawn to the centre of gravity of the element of spherical surface which serves as its base at a distance of $\frac{3}{4}$ of this radius from the centre. Suppose an auxiliary spherical surface described, with a radius equal to $\frac{3}{4}$ that of the sphere, and terminated in the cone which limits the sector, which spherical surface will be similar to that which forms the base of the sector. This auxiliary surface will cut all the pyramids, and the section obtained in each of them will have its centre of gravity at the same point as the pyramid. Hence it follows (Principle V) that the centre of gravity of the sector is the same as that of the auxiliary surface, and that consequently it is in the middle of the axis of this auxiliary zone. If R is the radius of the sphere and h the height of the spherical surface which forms the base of the sector, $\frac{3}{4}\,\mathrm{R}$ and $\frac{3}{4}\,h$ will be the radius and the height of the auxiliary portion. Calling the distance from the centre of gravity of the sector to the centre X, we have therefore $\mathrm{X} = \frac{3}{4}\left(\mathrm{R} - \frac{1}{2}\,h\right)$. If the sector is half a sphere, we have $h = \mathrm{R}$, and consequently $\mathrm{X} = \frac{3}{8}\,\mathrm{R}$.

A Body terminated by a Surface of Revolution.—Let O X, Fig. 3327, be the axis of revolution, and $y = f(x)$ the equation of the generating line A B. We may regard the whole volume as composed of elementary cylinders, as M P P′ l, having as a radius $\mathrm{M\,P} = y$, and a height $\mathrm{P\,P'} = d\,x$. The expression of one of these elementary cylinders is $\pi\,y^2\,d\,x$. If therefore we put $\mathrm{O\,C} = a$, and $\mathrm{O\,D} = b$, the abscissæ of the planes perpendicular to the axis serving as limits to the body under consideration, we shall have first, $\mathrm{V} = \pi \int_a^b y^2\,d\,x$, V being the volume of the body. The centre of gravity is upon the axis of revolution at a distance X from the origin, which will be given, in virtue of the theorem of the moments, by the relation $\mathrm{V\,X} = \pi \int_a^b y^2\,x\,d\,x$. Replacing y by its value and integrating, we obtain the unknown distance X.

A Body terminating in any Surface.—Suppose the body included between the two given surfaces $z_1 = \mathrm{F}(x, y)$ and $z_2 = f(x, y)$, the planes $x = a$, $x = a'$, and the planes $y = b$, $y = b'$. The element of the volume is the rectangular parallelepiped $d\,x\,d\,y\,d\,z$; the total volume V is therefore expressed by the relation

$$\mathrm{V} = \int_a^{a'} \int_b^{b'} \int_{z_2}^{z_1} d\,x\,d\,y\,d\,z = \int_a^{a'} \int_b^{b'} [\mathrm{F}(x, y) - f(x, y)]\,d\,x\,d\,y.$$

We have further, taking the moments of these elements with respect to the three co-ordinate planes,

$$\mathrm{V\,X} = \int_a^{a'} \int_b^{b'} \int_{z_2}^{z_1} d\,x\,d\,y\,d\,z = \int_a^{a'} \int_b^{b'} [\mathrm{F}(x, y) - f(x, y)]\,x\,d\,x\,.\,d\,y.$$

$$\mathrm{V\,Y} = \int_a^{a'} \int_b^{b'} \int_{z_2}^{z_1} y\,d\,x\,d\,y\,d\,z = \int_a^{a'} \int_b^{b'} [\mathrm{F}(x, y) - f(x, y)]\,d\,x\,.\,y\,d\,y.$$

$$\mathrm{V\,Z} = \int_a^{a'} \int_b^{b'} \int_{z_2}^{z_1} z\,d\,x\,d\,y\,d\,z = \int_a^{a'} \int_b^{b'} \frac{1}{2}\,\{[\mathrm{F}(x, y)]^2 - [f(x, y)]^2\}\,d\,x\,d\,y.$$

Any Volume.—In certain cases, in earthwork for example, it may be required to find the centre of gravity of a wholly irregular figure. We will suppose the case of a mound given by the projections of the curves of its level. The first step is to compute the area included under each of these curves. Let h be the distance of the consecutive planes of these curves. If this distance is not too great, and the curves do not vary too abruptly, we may consider each section included between two consecutive planes as a truncated pyramid, the volume of which may be determined by the known rule. Find the centres of gravity of the two bases; the centre of gravity of the section will be upon the straight line which joins these two centres, and it will divide this line in the proportion expressed by the formula [A]. Knowing thus the volume and the centre of gravity of each section, take the moments with respect to a horizontal plane and with respect to two rectangular vertical planes, and the rectangular co-ordinates of the centre of gravity of the mound will be obtained.

VIII. The centre of gravity possesses various properties, the most important of which is expressed by *Guldin's Theorem.*

1. *The volume of a truncated cylinder is equal to the product of its right section by the distance between the centres of gravity of its two bases.* Suppose, in the first place, the lower base to be the right section itself; take it as the plane of the $x\,y$'s, and let θ be the angle which the upper base makes with this plane. If Ω denote the total area of the upper base, and ω an element of this area, $\Omega \cos. \theta$ and $\omega \cos. \theta$ will denote the total area of the lower base and the element of this base corresponding to the element ω. Call the ordinate of the element ω, z. The volume of the cylinder which projects ω upon the plane of the base will be expressed by $\omega \cos. \theta \,.\, z$ within an infinitesimal of a superior order, and the volume of the truncated cylinder will consequently be expressed by $V = \Sigma\, \omega \cos. \theta \,.\, z = \cos. \theta \,.\, \Sigma\, \omega\, z$. But if Z is the ordinate of the centre of gravity of the upper base, we have, by the theorem of the moments, $\Omega\, Z = \Sigma\, \omega\, z$; therefore $V = \cos. \theta \,.\, \Omega\, Z$, that is, the volume sought is the product of the lower base $\Omega \cos. \theta$ by the ordinate Z of the centre of gravity of the upper base. But the foot of this ordinate is precisely the centre of gravity of the lower base, for if X denote the distance from the centre of gravity of the upper base to the plane of the $y\,z$'s and X' the distance from the centre of gravity of the lower base to this same plane, we shall have, to determine these two distances by, the equations $\Omega\, X = \Sigma\, \omega\, x$ and $\Omega \cos. \theta \,.\, X' = \Sigma \,.\, \omega \cos. \theta \,.\, x$; the second may be reduced to $\Omega\, X' = \Sigma\, \omega\, x = \Omega\, X$, whence $X = X'$.

It may be seen in the same way that these two centres of gravity are at the same distance from the plane of the $x\,z$'s; therefore they are upon the same line parallel to the axis of the z's, and the second is the foot of the ordinate of the first. The theorem is thus demonstrated for the case under consideration.

If the planes of the two bases are of any kind, we may divide the truncated cylinder, by a plane perpendicular to its edges, into two truncated cylinders which will come under the first case; and, by summing, we shall see that the measure of the volume is the right section multiplied by the sum of the ordinates of the centres of gravity of the two bases with respect to this right section, the foot of both of which ordinates is the centre of gravity of this section; this expression amounts therefore to the product of the right section by the distance between the centres of gravity of the two bases.

2. We will now consider any number of bodies the weights of which are p, p', p'', &c. We shall determine the centre of gravity of this system as if it were solid. Let ρ, ρ', ρ'', &c., be the distances from the respective centres of gravity of these bodies to the origin, R the distance from the centre of gravity of the system to this same origin; $\alpha, \beta, \gamma, \alpha', \beta', \gamma', \alpha'', \beta'', \gamma''$, &c., a, b, c, the angles which the straight lines upon which these distances are measured make with the three axes. Putting P for the total weight, we have, by the theorem of the moments,

$$P\, R \cos. a = \Sigma\, p\, \rho \cos. \alpha, \quad P\, R \cos. b = \Sigma\, p\, \rho \cos. \beta, \quad P\, R \cos. c = \Sigma\, p\, \rho \cos. \gamma. \quad [1]$$

These relations express that *if we apply to the origin, forces proportional to the products* $p\,\rho, p'\,\rho'$, $p''\,\rho''$, *&c., and respectively directed towards the centres of gravity of the partial bodies, they will have as a resultant a force proportional to the product* P R *and directed towards the centre of gravity of the system.* If the origin were the centre of gravity itself, the forces $p\,\rho, p'\,\rho', p''\,\rho''$, &c., would hold each other in equilibrium in this point, since the resultant would be nil.

3. If we square both members of the equations [1] and add them together member by member, we get $P^2 R^2 = \Sigma\, p^2 \rho^2 + \Sigma \,.\, 2\, p\, p'\, \rho\, \rho' (\cos. \alpha \cos. \alpha' + \cos. \beta \cos. \beta' + \cos. \gamma \cos. \gamma')$, or, calling the angle of ρ with ρ' $(\rho\,\rho')$, $P^2 R^2 = \Sigma\, p^2 \rho^2 + \Sigma\, 2\, p\, p'\, \rho\, \rho' \,.\, \cos. (\rho\,\rho')$. If r denote the distance of the centres of gravity of the bodies p and p', we have $r^2 = \rho^2 + \rho'^2 - 2\, \rho\, \rho' \cos. (\rho\,\rho')$, whence $2\, \rho\, \rho' \cos. (\rho\,\rho') = \rho^2 + \rho'^2 - r^2$, consequently $P^2 R^2 = \Sigma\, p^2 \rho^2 + \Sigma\, p\, p' (\rho^2 + \rho'^2 - r^2)$. Collecting all the terms in ρ^2, we have $\rho^2 (p^2 + p\, p' + p\, p'' + \ldots)$ or $\rho^2 \,.\, P\, p$; analogous terms would be found by collecting all those containing ρ'^2, then those containing ρ''^2, and so on. We may therefore write

$$P^2 R^2 = P\, \Sigma\, p\, \rho^2 - \Sigma\, p\, p'\, r^2. \qquad [2]$$

We conclude from this relation that *if the system be moved without changing its form, and in such a way that its centre of gravity remains always at the same distance from a fixed point (the origin), the sum of the products of the weights of the different bodies by the square of their distance from this fixed point, will remain constant.* For R being constant, as well as the distances represented by r, the term $P\, \Sigma\, p\, \rho^2$ must be constant, and consequently the same is true of $\Sigma\, p\, \rho^2$.

The relation [1] may be written $\Sigma\, p\, \rho^2 = P\, R^2 + \dfrac{\Sigma\, p\, p'\, r^2}{P}$; under this form, that the system retaining its form, that is, r, r', r'', &c., remaining constant, $\Sigma\, p\, \rho^2$ will be as small as possible when R is equal to zero; in other words, the centre of gravity possesses this property, namely, that *the* *sum of the products of the weights of the different bodies by the square of the distance from their partial centres of gravity to the centre of gravity of the system, is a minimum.*

IX. If all the material points forming a part of the system under consideration are in the same place, where the value of the acceleration g due to the weight may be regarded as constant, we may, in the equations of the moments, substitute the masses for the weights, and write

$$\mathrm{M\,X} = \Sigma\, m\, x, \quad \mathrm{M\,Y} = \Sigma\, m\, y, \quad \mathrm{M\,Z} = \Sigma\, m\, z.$$

If these different points are far enough from each other to make g vary sensibly, these equations cannot be deduced from the equations of the moments. But they define, nevertheless, the co-ordinates X, Y, Z, of a certain point in space, which plays an important part in the mechanics of free bodies, and particularly in astronomy. Euler proposed for this point the name of *centre of inertia;* other writers have proposed to call it the *centre of mass;* the name of *centre of gravity* has however predominated, though gravity is foreign to the determination of this point. Care must be taken, in order to avoid confusion, to distinguish the case in which the weights are proportional to the masses, from that in which this proportion has no existence.

Movement of the Centre of Gravity.—When a material system is in motion, its centre of gravity is generally in motion too; and this motion may be determined when that of each of the material points which make up the system is known. The determination of this is the object of a theorem known as the *Principle of the motion of the centre of gravity*, which we will now establish.

I. Let p, p', p'', &c., be the weights of the material points of which the material point under consideration is composed, x, x', x'', &c., their distances from a plane of comparison, P the total weight of the system, and X the distance of its centre of gravity from the same plane. We shall have by the theorem of the moments of parallel forces,

$$p\,x + p'\,x' + p''\,x'' + \ldots = \mathrm{P\,X}. \qquad [1]$$

But if all the points of the system are in a space so limited that the acceleration g due to the weight is the same for all these points, we may, dividing all the terms of the relation [1] by g, substitute the masses for the weights, and write

$$m\,x + m'\,x' + m''\,x'' + \ldots = \mathrm{M\,X}. \qquad [2]$$

In this relation, the quantities x, x', x'', &c., X vary with the time, and may be considered as functions of this variable. Differentiating with respect to the time, we have

$$m\frac{d\,x}{d\,t} + m'\frac{d\,x'}{d\,t} + m''\frac{d\,x''}{d\,t} + \ldots = \mathrm{M}\,\frac{d\,\mathrm{X}}{d\,t}\,.$$

But $\frac{d\,x}{d\,t}$ is the component, perpendicular to the plane of comparison, of the velocity of the point whose mass is m; we will represent it by v_x. Also $\frac{d\,x'}{d\,t}$ is the component, in the same direction, of the velocity of the point whose mass is m'; we will represent it by v'_x, and so on with the others. Similarly $\frac{d\,\mathrm{X}}{d\,t}$ is the component, perpendicular to the plane of comparison, of the velocity of the centre of gravity; we will represent it by V_x. By means of these notations, the above relation may be written, $m\,v_x + m'\,v'_x + m''\,v''_x + \ldots = \mathrm{M\,V}_x$, or, abridging the expression,

$$\Sigma\, m\, v_x = \mathrm{M\,V}_x, \qquad [3]$$

that is, *the sum of the quantities of movement of the whole system, projected upon an axis perpendicular to the plane of comparison, is equal to the quantity of movement of the centre of gravity, projected upon the same axis* (if we attribute to the centre of gravity a mass equal to the total mass of the system). If we consider the system with reference to three rectangular axes, of the x's, of the y's, and of the z's, and project the quantities of movement successively upon these three axes, we shall obtain, for the axes of the y's and the z's, two other equations analogous to the equation [3], namely,

$$\Sigma\, m\, v_y = \mathrm{M\,V}_y\,, \qquad [4]$$

$$\text{and} \qquad \Sigma\, m\, v_z = \mathrm{M\,V}_z\,. \qquad [5]$$

The equations [3], [4], and [5] will determine the velocity V of the centre of gravity; for we deduce first, $\mathrm{V}_x = \frac{\Sigma\, m\, v_x}{\mathrm{M}}$, $\mathrm{V}_y = \frac{\Sigma\, m\, v_y}{\mathrm{M}}$, $\mathrm{V}_z = \frac{\Sigma\, m\, v_z}{\mathrm{M}}$. We shall have further

$$\mathrm{V} = \sqrt{\mathrm{V}^2_x + \mathrm{V}^2_y + \mathrm{V}^2_z}\,,$$

and if α, β, γ, denote the angles which this velocity makes with the axes,

$$\cos.\ \alpha = \frac{\mathrm{V}_x}{\mathrm{V}}\,, \quad \cos.\ \beta = \frac{\mathrm{V}_y}{\mathrm{V}}\,, \quad \cos.\ \gamma = \frac{\mathrm{V}_z}{\mathrm{V}}\,.$$

II. The equations [3], [4], and [5] are, besides, susceptible of a remarkable interpretation. The quantity of movement of a material point is a number of kilogrammes; we may therefore always conceive a force which has the same direction as the velocity of the body in motion, and whose intensity is expressed by its quantity of motion. Let ϕ, ϕ', ϕ'', &c., be the forces which would thus represent the quantities of motion of the various material points of the system, Φ the force which, in like manner, would represent the quantity of motion of the centre of gravity; let ϕ_x, ϕ'_x, ϕ''_x, &c., Φ_x, be the projections of these forces upon the axis of the x's, respectively equivalent to the quantities of motion projected upon the same axis, or to $m v_x$, $m' v'_x$, $m'' v''_x$, &c., M V_x. In virtue of the equation [3] we shall have $\Sigma \phi_x = \Phi_x$. We should have likewise for the other two axes $\Sigma \phi_y = \Phi_y$ and $\Sigma \phi_z = \Phi_z$. But these last three equations denote that the force Φ is the resultant of the forces ϕ, ϕ', ϕ'', &c. The equations [3], [4], and [5] denote that *the quantity of motion of the centre of gravity is the resultant of the quantities of motion of the various points of the system transferred parallel to each other to this point* (supposing the quantities of motion to be composed like the forces).

III. This relation exists at any instant during the motion, and consequently also at the instant of initial motion. So that if we denote by the index *zero* the initial velocities, we shall have, in virtue of the equations [3], [4], [5] themselves,

$$\Sigma m v_{0x} = \mathrm{M}\,\mathrm{V}_{0x}\,, \qquad [6]$$

$$\Sigma m v_{0y} = \mathrm{M}\,\mathrm{V}_{0y}\,, \qquad [7]$$

$$\Sigma m v_{0z} = \mathrm{M}\,\mathrm{V}_{0z}\,. \qquad [8]$$

Subtracting member by member the equations [6], [7], [8] from the equations [3], [4], [5], we obtain

$$\Sigma m v_x - \Sigma m v_{0x} = \mathrm{M}\,\mathrm{V}_x - \mathrm{M}\,\mathrm{V}_{0x}\,, \qquad [9]$$

$$\Sigma m v_y - \Sigma m v_{0y} = \mathrm{M}\,\mathrm{V}_y - \mathrm{M}\,\mathrm{V}_{0y}\,, \qquad [10]$$

$$\Sigma m v_z - \Sigma m v_{0z} = \mathrm{M}\,\mathrm{V}_z - \mathrm{M}\,\mathrm{V}_{0z}\,. \qquad [11]$$

But in virtue of *the principle of the quantities of motion, or of the effect of impulse*, we have

$$\Sigma m v_x - \Sigma m v_{0x} = \int_0^t \mathrm{R}_x\, d t,$$

$$\Sigma m v_y - \Sigma m v_{0y} = \int_0^t \mathrm{R}_y\, d t,$$

$$\Sigma m v_z - \Sigma m v_{0z} = \int_0^t \mathrm{R}_z\, d t,$$

R denoting the *resultant of translation* of the external forces soliciting the system; we may therefore write

$$\left.\begin{aligned} \mathrm{M}\,\mathrm{V}_x - \mathrm{M}\,\mathrm{V}_{0x} &= \int_0^t \mathrm{R}_x\, d t \\ \mathrm{M}\,\mathrm{V}_y - \mathrm{M}\,\mathrm{V}_{0y} &= \int_0^t \mathrm{R}_y\, d t \\ \mathrm{M}\,\mathrm{V}_z - \mathrm{M}\,\mathrm{V}_{0z} &= \int_0^t \mathrm{R}_z\, d t \end{aligned}\right\} \qquad [12]$$

But these equations are those of the motion of a material point whose mass is M, whose initial velocity is V_0, and which is subjected to a force R. Therefore we may say, *the centre of gravity of a material system moves as if the whole mass of the system were concentrated in it, as if the resultant of translation of all the external forces were applied to it, and as if all the quantities of initial motion had been transferred to it parallel to each other and composed like forces.* Such is the principle of the movement of the centre of gravity.

IV. This principle does not depend upon the *mutual* forces which are exerted between the various material points of which the system is composed. From this observation, several consequences are deduced :—

1. Suppose a spherical bomb thrown into space; its centre will describe a trajectory in the vertical plane passing through the direction of the initial velocity. Suppose also that at a certain instant the bomb bursts; as the explosion is due merely to the interior mutual forces which are developed, these forces will not alter the motion of the centre of gravity; and if it were possible to determine at each instant the centre of gravity of the system formed by the fragments of the bomb, we should see that this point continues to describe the trajectory which the centre of the whole bomb was describing before the explosion occurred.

2. The equations [12] explain also the effects of the *recoil* in fire-arms. Let us take as an example a piece of cannon standing upon a horizontal soil with its carriage. Previous to the explosion the system was subjected merely to its own weight, and to the reactions of the ground, producing a resultant equal and contrary to this weight; and these forces passing through the centre of gravity gave a total resultant equal to zero. The explosion being due solely to mutual molecular forces, the resultant of translation R remains nil; in virtue of the equations [12], which in this case are reduced to one. If we take as the axis the horizontal direction of the shot, the final quantity of motion is equal to the initial quantity of motion; but this was nil; the final quantity of motion is therefore nil also. Denoting the mass of the ball by m, its velocity by v, the mass of the piece and its carriage by M, and the velocity of the recoil by u, we have $m v - \mathrm{M} u = 0$,

whence $u = v \,.\, \frac{m}{M}$, that is, the initial velocity of the recoil would be a fraction of the initial velocity of the ball (in the heart of the piece) marked by the ratio between the mass of the ball and that of the piece with its carriage. In reality the velocity of the recoil is a little less, on account of the friction of the carriage upon the ground, that of the wheels upon their bearings, and that of the ball against the inner surface of the piece.

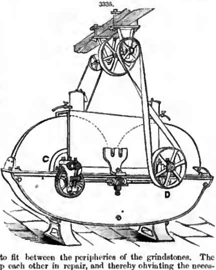
3. In general, whenever there are no external forces, or when the external forces give a resultant of translation equal to zero, the second members of the equations [12] are nil, and the final quantity of motion of the centre of gravity is equal to its initial quantity. If the centre of gravity were originally at rest, it would remain at rest; if it possessed a certain velocity, it would retain that velocity, and move with a rectilinear and uniform motion.

4. An animal cannot move without the aid of the reactions exerted by the bodies with which it is in contact. Placed in space, and being in contact with no kind of body, it would vainly exert itself to move its centre of gravity.

5. The equations [12] also explain the effect of a *couple*. The two equal and contrary forces which form the couple give a resultant of translation equal to zero; consequently the couple has no influence upon the motion of the centre of gravity. If this point were originally at rest, it would remain at rest; and the motion produced by the couple can be merely one of rotation about an axis passing through the centre of gravity. See DAMMING.

GRINDSTONE. FR., *Meule, Pierre à aiguiser*; GER., *Schleifstein*; ITAL., *Mola*; SPAN., *Piedra de afilar*.

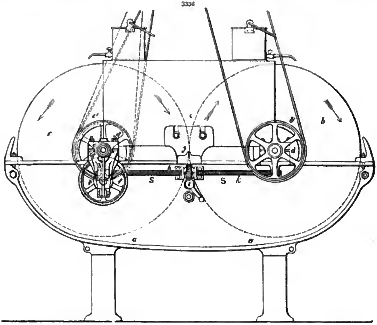
3335.



W. Muir's Apparatus for Grinding Edge Tools and other Articles.—This arrangement, Figs. 3335, 3336, consists in having two grindstones working in the same trough, and in supporting the shafts of the grindstones in bearings connected by a screw, which has a right-hand thread at one end, taking into a nut fixed to one bearing, and a left-hand thread taking into a nut in the other bearing. The grindstones are in contact with each other, and they are made to revolve in contrary directions, but at different velocities, so as to produce a rubbing action at the point where the peripheries are in contact; or the grindstones may be made to revolve in the same direction to produce the same rubbing action, the effect and object of which is to cause the inequalities on the periphery of one grindstone to be removed by the action of the other. A slight lateral motion is given to one or both of the grindstones, to assist in making the peripheries wear equally. The lateral motion may be given by a worm fixed on the grindstone shaft, taking into a worm-wheel, in the face of which is a crank-pin, giving motion to a lever, the vibrating end of which is connected to the end of the shaft by a clip. In some cases the grindstones may be made to swivel partly round, for the purpose of keeping the periphery true; or a piece of stone or other suitable material, moving to and fro, may be made to fit between the peripheries of the grindstones. The object is to cause the grindstones to keep each other in repair, and thereby obviating the necessity of turning the peripheries of grindstones when they become uneven, owing to the inequalities in the hardness of the surface.

Fig. 3335 is a front elevation, and Fig. 3336 is a longitudinal, of one of Muir's grindstones. In Fig. 3336, *a* is a trough, which may be made of cast iron or other suitable material; *b* and *c* are two grindstones, revolving in bearings or pedestals *d*, bolted to the flanches of the trough *a*. The peripheries of the grindstones are in contact at the point *e*. One of these grindstones is driven by an open strap passing round the pulley b^1, and the other by a crossed strap passing round the pulley c^1. C D, Fig. 3335, show how the belts and pulleys are geared. When the grindstones are of the same diameter, the pulleys must be of different diameters, in order that there may be a rubbing action between the peripheries of the grindstones. This rubbing action has a tendency to keep the peripheries of both the grindstones cylindrical; but in order to produce this result more effectually, a lateral as well as a rotary motion are given to one or both of the grindstones, in the following manner:—Upon the shaft of the grindstone *c* is fixed a spur-pinion c^4, which gears into another pinion *f*, revolving on a stud fixed in a bracket d^1, bolted to one of the pedestals *d*; to the pinion *f* is fixed a boss, with a spiral groove f^1; in this groove a stud, projecting from the link *g*, enters; this link is supported in the bracket d^1, and its outer end is jointed to the lower end of the lever *h*; this lever vibrates on a stud fitting in the bracket d^1; its upper end is forked, and takes into a groove in the shoulder c^2, which is also fixed on the shaft of the grindstone *c*. By this arrangement it is evident that the rotary and lateral motions of the grindstone are simultaneous; for the pinion c^4 drives the pinion *f*, which in revolving moves the link *g* to and fro. This motion is communicated to the lever *h*, and by it to the grindstone. When the grindstones diminish in diameter, the bearings *d* in which they revolve are gradually brought closer together, so as to keep the peripheries in contact, by the attendant turning the shaft *i*. This shaft is furnished with two

3336



worms taking into the wheels *j*, fixed on the screws *k*; each of these screws is made with a right-handed thread at one end, and a left-handed thread at the other; consequently, when the shaft *i* is turned in one direction it causes the pedestals *d* to approach, and when turned in the other direction it causes them to recede from each other; the rubbing produced by the peripheries of the grindstones moving at different velocities, and by the lateral motion, causes the inequalities on the peripheries of one stone to be removed by the other, thereby keeping them both in working condition. Instead of making the peripheries of the grindstones revolve at different velocities, and of giving a lateral to-and-fro motion to one or both of them, in some cases we may introduce a flat piece of stone, or other suitable material, between the peripheries of the grindstones at the point *e* in Fig. 3336, and give a to-and-fro motion to this piece of stone, the action of which on the peripheries of the grindstones would keep them true. The same object may also be obtained by causing one or both of the grindstones to swivel partly round, so as to produce a rubbing action on their peripheries. The stones may also be driven so that they revolve in the same direction; the peripheries at *e* in Fig. 3336 would then run in opposite directions, as shown by the arrows.

GRIST-MILL. Fr., *Moulin à drêche*; Ger., *Schrotmühle*; Span., *Molino para trigo.*

See Mills.

GROUND-AUGER. Fr., *Tarière à fond*; Ger., *Grundbohrer*; Ital., *Trivella*; Span., *Sonda.*

See Augers.

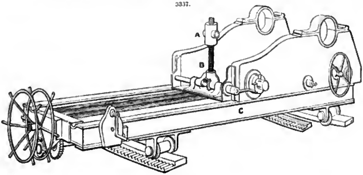
GUDGEON. Fr., *Tourillon*; Ger., *Drehzapfen*; Ital., *Perno*; Span., *Pivote.*

A *gudgeon* is the piece of iron in the end of a wooden shaft, on which it turns in a collar or on a gudgeon-block; formerly the part of any horizontal shaft on which it runs.

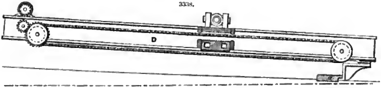
GUN-CARRIAGE. Fr., *Affût de canon*; Ger., *Geschütz Rampert*; Ital., *Affusto*; Span., *Cureña.*

Captain Scott's Gun-Carriage for Heavy Naval Ordnance.—Simple as the invention of a suitable gun-carriage for heavy naval ordnance may appear, yet, in attempting this apparently easy task, before R. A. E. Scott succeeded in accomplishing it, many ingenious inventors failed. Fig. 3337 represents Scott's 300-pounder carriage and slide. The running-in-and-out gear is shown in Fig. 3338, and consists of two endless chains, stretched over two pitch-wheels on each side of the slides, with a screw arrangement for tightening the chains. When the gun is required to be run in, the outside part, or toes, of the compressor-levers are pressed against the lower part of the box, as shown in Figs. 3338 and 3340, which is serrated on its upper edge, so as to fit between the pins of the chain links, and press them up against the serrated edge of the upper box. By this means several of the pins of the chains are securely held by the whole force of the compressor *a a*, Fig. 3340; and as both parts of the box which clutch them are attached to the carriage, it is only necessary to turn the purchase at the rear end of the slides to draw the gun in or out. When either operation is finished, the handle of the compressor is turned, and the inner part, or heel, of the compressor-levers then performs the work of compressing. Thus one compressor performs the double duty of holding the gun on recoil, and of clasping the chains on both sides of the slide together with equal certainty and security; and this gear being always in place, and out of the way of every other working part, overcomes one of the difficulties previously experienced in working heavy guns at *sea*. Scott's carriage is fitted with two compressors, under the idea—however powerful and strong the working part may be—it is not safe to depend upon a single part.

3337.



3338.



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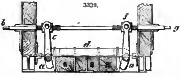

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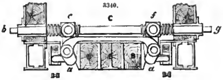
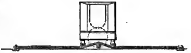


The fore compressor *b c a d a f g*, Fig. 3339, forcing the beams B, B, B, together, and retaining them firmly in their places, is more powerful than the aft compressor shewn in Fig. 3340. The fore compressor is placed on a higher level than the other, and hence the upper arms *a c*, *a f*, are longer than those shown in the aft compressor, Fig. 3340. The shaft *b g* upon which these arms work passes through each side of the carriage, and projects beyond; it is provided with a right and left-handed screw, to which motion is given by turning a handle shipped upon the shaft at either side of the gun, and thus opening or closing the lever-arms. The fore compressor is applied when extra holding power is required, and is useful as an additional means of readily checking the gun when running in or out in a heavy roll. Scott's plan of raised racers was adopted in H.M.'s ships Research, Minotaur, and Bellerophon, but in both the latter ships the centres of the racers were let down into the deck $\frac{3}{4}$ of an inch, and their ends raised so as to admit the guns to be trained round on a horizontal plane. The edges nearest the ship's side of the front racers were slotted to receive a strong hook *d*, Fig. 3338, which held the slide securely down to the deck, and rendered the gun secure in any sea. In the Minotaur, as well as in the Research, the front of the slide was further secured by a massive metal block, working in a grooved racer; but after the trial of firing a 12-ton gun nineteen times at the top of the roll in the Minotaur without this fastening, it was considered unnecessary, more especially as a pivot-bar, or flap, of the same strength as the usual service elongated V-flap, had been fitted to the pivot-point in the port as a preventer. In the Minotaur, a gun on this mounting trained 31° each way; but no other gun with the V-flap and fixed pivot obtained so much as 29°. A similar result was observed in the Bellerophon, where, although the port was closed up from 2 ft. 9 in. to 2 ft. 1 in., the training was still 31° each way. The training of the other guns in 2 ft. 9 in. apertures was only 30°. Fig. 3341 shows how the Minotaur's port was closed on the lower side 14 in., the corners being rounded and made much higher.

3341.



The application of this important feature of Scott's system of mounting had a similar effect to throwing the lower port-sill a mean of 16 in. higher out of the water, thus adding greatly to a vessel's capabilities of fighting in a sea-way. Had a small half-port been fitted up, 7½° of depression could have been obtained in the Bellerophon, and 9° in the Minotaur, when wanted. This woodwork rendered protection to the loaders against the spray of the sea; nor was any disadvantage found, but the contrary, from closing up the port, the rapidity of the fire in the Minotaur with the 150-lb. ball being more than double that previously obtained, and the quickness in the Bellerophon, with the 250-lb. rifled shot, being equally unmatched. The elevating gear A B C, Fig. 3337, consists of a screw worked through a box, fitting inside another box which is fastened to the gun. These boxes have a washer interposed between their surfaces, and the outer box is open at the bottom; hence, when the gun is fired with its muzzle above the upper port-sill, the outer box is lifted several inches up from its resting place on the inside box, when the muzzle dipped under the port-sill, and then dropped easily down again upon the washer on the top of the inner box. By this contrivance the weight of the breech of the gun is received without any damaging shock, and the jar of the discharge is absorbed likewise. Any fixed elevation can also be given and maintained with certainty in bombarding. Motion is communicated to the screw through two bevelled wheels, shown at B, Fig. 3337, suitably supported upon the bottom of the carriage. By means of handles worked upon each side, a rapid touch may be given in elevating the gun; in case the captain should find it rolling up or down, his sights would not come on with the object to be fired at.

Running-in-and-out Eccentrics.—For Scott's carriage, eccentrics, which had to stop to allow them to pass the centre, and remain fixed in that position, were devised. This prevented the necessity of having the men to hold on to them in running the gun in or out; the arrangement also allows the crew on each side to hold on by the ropes which were attached to the ends of the levers of the eccentrics, if required, and so keep the eccentrics ready to drop the carriage off its rear rollers or trucks. The levers which work the eccentrics are upon the sides of the carriage, and so fitted that the screw is prevented from injury in case the gun should go off in being run out. Should the eccentrics be slacked up, the carriage would drop upon the slides, with a surface of wood everywhere touching a surface of iron, as dropping the rear of the carriage lifts the front trucks off the slides; and as both these surfaces are rough, there would then be an absence of sliding sufficient to keep the carriage and gun from moving in a roll. The lever-handles are fitted with bands round the drumhead of the eccentrics, which hold them securely when the levers are let drop out of use. In consequence of these arrangements, every part of the mounting is in place, ready for use; the man who is termed No. 7, having no mechanical labour to perform, can give his whole attention to keeping the gun pointed upon the object, which can be done by means of the rack and pinion, so steadily as not to interfere with the loading. The requisite elevation in case of a change in the heel of the ship can also be given with the same ease and steadiness; and all these operations can be performed simultaneously.

The rear compressor, Fig. 3340, being on a lower level than the fore one, Fig. 3339, and being also considerably below the level of the proposed height for the lower port-sill, would probably escape injury should the front compressor be hit. Although the rear compressor is less powerful, it is more important than the other, being employed to catch the chains in running the gun in and out, and being also the principal working compressor for holding the gun on being fired. The only addition made to this compressor, to enable it to perform also the duty of clutching the chain, consists of small pieces, or toes, on the outside of the lever-arms *o a*, *f a*, Fig. 3340. These toes are shown at *a a*, Fig. 3340, in which the rear compressor is shown in section, compressing the balks B, B, B, preparatory to firing, and consequently with the toe-pieces at *a a* clear of the lower box. The balks of wood B, B, B, upon which the compressors act are slightly tapered longitudinally towards the front of the slide, and are very much tapered in their depth.

The Moncrieff System of Gun-Carriage.—We shall in this place only explain the Moncrieff system of working artillery as far as it relates to coast defence.

This system is based on sound philosophical principles, and may be investigated under the three following heads;—

1st. The mechanical principle of the gun-carriages.

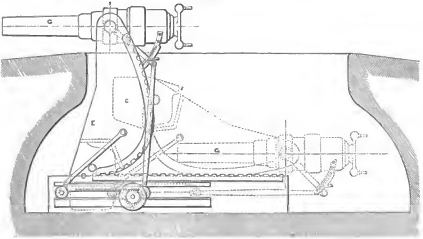
2nd. The form internal and external of the batteries.

3rd. The selection of ground for placing the batteries, and the arrangement for working them to the greatest effect; or, in other words, the *tactics* of defence for positions where the system is employed.

The principle on which the carriage, Fig. 3342, is constructed is the first and most important part of the new system, because on it depends the possibility of applying the other parts. This principle may be shortly stated as that of utilizing the force of the recoil in order to lower the whole gun below the level of the crest of the parapet, so that it can be loaded out of sight and out of exposure, while retaining enough of the force above referred to to bring the gun up again into the firing or fighting position. This principle belongs to all the carriages; but the forms of these carriages, as well as the method in which this principle is applied, vary in each case. For instance, in siege guns, where weight is an element of importance, the recoil is not met by counterpoise.

With heavy garrison guns, on the other hand, which when once mounted remain permanent in their positions, there is no objection to weight. In that case, therefore, the force of gravity is used to stop the recoil, because it is a force always the same, easily managed, and not likely to go wrong; and as these carriages are employed for the most powerful guns, it is a great advantage to have the most simple means of working them.

3342.



Formerly the principal difficulty arose from the enormous and hitherto destructive force of the recoil of powerful guns; and here we shall point out the manner in which that difficulty is overcome.

That part of the carriage, E, which is called the elevator may be spoken of and treated as a lever; this lever has the gun-carriage axle at the end of the power-arm, and the centre of gravity of the counter-weight C at the end of the weight-arm, there being between them a moving fulcrum.

When the gun G is in the firing position, the fulcrum on which this lever rests is almost coincident with the centre of gravity of the counter-weight C, and when the gun is fired the elevators roll on the platform, and consequently the fulcrum, or point of support, travels away from the end of the weight-arm towards the end of the power-arm, or, in other words, it passes from the counter-weight C towards the gun G.

Notice the important result of this arrangement.

When the gun is fired, its axle passes backwards on the upper or flat part of a cycloid. · It is free to recoil, and no strain is put upon any part of the structure, because the counter-weight commences its motion at a very low velocity. As the recoil goes on, however, the case changes completely, for the moving fulcrum travels towards the gun, making the weight-arm longer and longer every inch it travels. Thus the resistance to the recoil, least at first, goes on in an increasing progression as the gun descends, and at the end of the recoil it is seized by a self-acting pawl or catch.

The recoil takes place without any jar, without any sudden strain, and its force is retained under the control of the detachment to bring up the gun to the firing position at any moment they may choose to release it. The recoil, moreover, however violent at first, does not put injurious horizontal strain on the platform. In Captain Moncrieff's experiments at Edinburgh with a 32-pounder, he found that so slight was the vibration on the platform caused by firing, that the common rails on which the elevators rolled in that experiment, and which were only secured in the slightest manner, did not move from their position; nor even when heavy charges or double shot were used, did sand and dust fall off their curved tops. See p. 1716.

At a still earlier experiment made with a model of a 95-cwt. gun, the model was fired on the ice with excessive charges, and nevertheless remained stationary.

This valuable concomitant of the system cannot be appreciated fully without referring to the difficulties that have been experienced, and are now felt, in getting pivots, platforms, &c., on the ordinary system strong enough to mount the new artillery, where the recoil is stopped by friction applied directly by means of what are technically called *compressors* attached to the platform. See BATTERY. ORDNANCE.

GUN-COTTON. FR., *Coton azotique;* GER., *Schiessbaumwolle;* ITAL., *Pirosillina;* SPAN., *Algodon-pólvora, Piroxilina.*

See GUNPOWDER.

GUN-METAL. FR., *Métal de canon;* GER., *Kanonenmetall;* ITAL., *Bronzo;* SPAN., *Metal de cañones*

See ALLOYS. ARTILLERY.

GUNNERY. Fr., *Science de l'artillerie*; Ger., *Artillerie Wissenschaft*; Ital., *Artiglieria*; Span., *Ciencia del artillero.*

Gunnery is that department of military science which comprehends the theory of projectiles and the manner of employing *ordnance.*

When great minds conspire to perpetuate a fallacy, it has always been a difficult matter to clear that fallacy away. We know of no subject capable of being submitted to mathematical investigation that has received a greater amount of fallacious treatment, and that too, by great minds, than the motion of projectiles. Besides, school-taught pedants, thimble-rigging with mathematical symbols, reduced this branch of military science to a deplorable state of uncertainty, and left the artillerist to play a game of blindman's-buff with his guns. Initial velocities have been little more than guessed at, the resistance of the air overrated, and the force of gravity misstated. It is well known that General Anstruther's physical courage is great, but, with these facts before him, his moral courage must be as great as his physical, to propound and develop a new system of gunnery; but "his heart is in his work, and the heart giveth grace unto every art." The system introduced by General Anstruther, which is practical and easily applied, must give correct results within the range of his experiments, without offering any special theory about initial velocities, the resistance of the air, or the force of gravity; indeed, in Anstruther's system are collected all these elements.

In the following fifty-eight paragraphs Major-General P. Anstruther lays the foundation, and illustrates the practical application of his system.

In the first paragraph he denies the difficulty of drawing the trajectory of a projectile.

2. Defines what it is that we want to do.

3. States our want of data for the purpose.

4. Expresses a wish that we may get them.

5. Describes our intended demonstration.

6. Shows how Colonel Boxer says it is to be done, algebraically.

7. Admits his demonstration, but requires it in numerals.

8. Names an elevation and time of flight, 45° and 27·1 seconds.

9. Gives the ascent, descent, and range, in a vacuum.

10. Defines Fig. 3343, the triangle for the given elevation.

11. Graduates the ascent of this triangle, unresisted.

12. Graduates the descent of this triangle, unresisted.

13. Proposes comparison with recorded fact.

14. States the recorded range for elevation 45° in 27·1 seconds.

15. Shows the reduction produced by the resistance of the air.

16. Infers the power of measuring the resistance.

17. Shows the value of $\frac{1}{2}g$ for 27·1 seconds of time.

18. Shows the varying value of $\frac{1}{2}g$, as printed years ago.

19. Shows where this may be had, printed, *in extenso.*

20. Assumes that we now know the true law of gravity.

21. Defines Fig. 3344, a parallelogram on Fig. 3343.

22. Defines the two lines added.

23. Applies the law of the composition and resolution of forces.

24. Why applied to our question.

25. Requires the graduation of the vertical descent.

26. Shows the graduation of the descent the same for all elevations.

27. The graduation of the vertical ascent varying with elevation.

28. At 90° elevation the two coincide exactly.

29. Proposes to apply this to our example.

30. Shows place of ball at end of 27·1 seconds, elevation 90°.

31. Shows additional time to be required for descent.

32. Shows that this will equally increase time of ascent.

33. Tries an addition of 6·9 seconds, it is too much.

34. Tries an addition of 6·8 seconds, which will do.

35. Therefore 27·1 + 6·8 = 33·9 seconds is the time for elevation 90°.

36. Therefore 761 ft. per second is the initial velocity.

37. Shows graduation of descent, for 0·9, 1·9, 2·9, 3·9, &c., &c., to 33·9.

38. Shows graduation of ascent, the inversion of the descent.

39. Describes Table A.

40. Shows how to draw the trajectory.

41. Shows the French Table of Ranges for 45° elevation with velocities.

42. Selects one for comparison with our theory, 10,699 ft.

43. Deduces the time of flight, and shows the oblique ascent.

44. Shows that 35·32 seconds is the time for elevation 90°.

45. Shows that 777 ft. a second is the velocity, compared with 784 ft. a second.

46. Shows that Table B gives ranges at 45° with velocities.

47. Shows the application of the instrument, Fig. 3345.

48. Supposes an example. Elevation 5°, range 1000 yds.

49. Works it out by the instrument, velocity 777 ft. a second.

50. Describes the method of working it out.

51. Shows the limits beyond which our data will not carry us.

52. Quotes a range from a Text-Book, a French range.

53. Puts it into English feet.

54. Shows the vertical descent and oblique ascent and time.

55. Finds the mean velocity.

56. Refers to Table C.

57. Finds the time for the mean velocity.

58. Deduces the final velocity and initial velocity.

1. There would be no difficulty whatever in determining the trajectory of any projectile, if the artillery officers could be persuaded to deduce the laws of their own science, gunnery, from the

recorded results of their own practice, instead of intrusting this, their first, and most important of all duties, to the professors of mathematics.

2. These men, however able and eminent, do not know what it is that the artillery require; they teach us how to calculate the trajectory for given elevation with given initial velocity; what we want to know is, how to determine the initial velocity from given range and elevation.

3. And this we could easily do if we had the data: but no book, either in the French or English language, affords reliable record of range for elevation with time of flight exceeding 31 seconds; we cannot therefore determine the trajectory for any initial velocity exceeding 800 ft. per second; but within that limit we can do it without any difficulty.

4. We shall offer one example, fully worked out, in the hope that the official advisers of governments may yet be induced to recommend the few, and comparatively cheap, additions to our practice tables, which are required to complete our professional knowledge; the results of private practice, under any circumstances, fail to carry with them the weight of authority requisite to establish the laws of science; were it otherwise, the experiments required should have been furnished long ago.

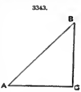
5. In working out the example selected, we shall show what would be the trajectory of a projectile, if not resisted by the atmosphere, and then we shall compare that calculation with the recorded results of actual practice with the same elevation, in the same time of flight.

6. To find the trajectory of a projectile in a vacuum, Colonel Boxer, in his treatise on Artillery, tells us, on p. 87, that we have only to "compound the motion produced by gravity, which, by the second law of motion, is the same as it would produce upon a body at rest, with the uniform motion in the line" of direction, "in order to obtain the actual motion of the shot upon the hypothesis assumed," that hypothesis being the leaving out of consideration for the present the resistance of the atmosphere.

7. Colonel Boxer proceeds to prove, algebraically, that the curve resulting is a true parabola. We accept his demonstration, but for our present purpose it is necessary to show, by the use of numerals, the application of this theory to some specified elevation and time of flight, to enable us to draw a comparison between the curve of calculation and the recorded results of actual practice.

8. For this purpose let us suppose a ball fired at 45° elevation, seen to strike the plane at the expiration of 27·1 seconds of time of flight: putting out of consideration for the present the resistance of the atmosphere, we are to draw the trajectory of this ball; we know that it is a parabola, but we require to show its measurements.

3343.



9. The time of flight being 27·1 seconds, the fall by gravity, unopposed by the atmosphere, will be equal to $27\cdot1^2 \times 16\frac{1}{12} = 11811\cdot76$ ft., and as the elevation is 45°, the horizontal range will be equal to the vertical descent, which is the fall by gravity, therefore the horizontal range is also 11811·76 ft., and the oblique ascent is the square root of the sum of the squares of these two, it is 16704·35 ft.

10. Let A B G, Fig. 3343, be a right-angled triangle, in which the sides are respectively 11811·76 ft., 11811·76 ft., and 16704·35 ft.; within these three lines we are to inscribe the trajectory of a ball fired from A, towards B, seen to strike G at the expiration of 27·1 seconds of time; leaving out of consideration for the present, the resistance of the atmosphere.

11. We divide the length of A B by the time of flight, the quotient $\frac{16704\cdot35}{27\cdot1} = 616\cdot396775$ ft. a second, is the uniform velocity of the oblique ascent; we therefore lay off upon A B, in succession from A, 27 equal spaces, each 616·396775 ft., to show the uniform motion in the line of direction, with which, as Colonel Boxer tells us, we are to compound the motion produced by gravity.

12. From each of the points so marked, in succession, we let fall a perpendicular, denoting by its length the fall by gravity, $t^2 \times 16\frac{1}{12}$ ft., in the number of seconds of time, t, elapsed since the ball left A on its passage towards B; a line joining the lower ends of all these perpendiculars is the trajectory required, the parabola.

13. We are now to compare this with recorded fact.

14. The 13-in. sea-service iron mortar, at elevation 45°, with a charge which gave 27·1 seconds time of flight, had a range of only 3327 yds., or 9981 ft.; if we apply this to Fig. 3343, we have A G = 9981 ft., B G = 9981 ft., and A B = 14115·26 ft.

15. Each side has been reduced by the resistance of the atmosphere in the proportion of 11811·76 to 9981 ft. in 27·1 seconds.

16. Such a reduction in the magnitude of B G, the fall by gravity in the time of flight, affords us a ready measure of the effect of the resistance of the atmosphere.

17. The fall by gravity in 27·1 seconds of time would be, in a vacuum, equal to $27\cdot1^2 \times 16\cdot083333 = 11811\cdot76083333$, and in the atmosphere it is $27\cdot1^2 \times 13\cdot590501 = 9980\cdot99983941$; this last we shall call $27\cdot1^2 \times 13\cdot59$.

18. It is some years since General Anstruther offered to the service Table D, showing the fall by gravity as modified by the resistance of the atmosphere, in which the varying value of the multiple of the square of the time was deduced from the measure of the fall in 27·1 seconds as follows, namely;—

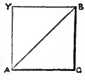
For 3 seconds of time the fall is $3^2 \times 16$
13 " " $13^2 \times 15$
23 " " $23^2 \times 14$
24 " " $24^2 \times 13\cdot9$
25 " " $25^2 \times 13\cdot8$
26 " " $26^2 \times 13\cdot7$
27 " " $27^2 \times 13\cdot6$
27·1 " " $27\cdot1^2 \times 13\cdot59$, as above.

19. Table D shows the fall by gravity, together with the velocity which a ball would acquire by the fall, for the tenth parts of seconds of time from one-tenth of one second to fifty seconds.

20. We shall now suppose the true graduation of B G, the vertical descent in Fig. 3343, to be known to us; we shall deduce from it the graduation of the oblique ascent A B, the first step of which, when found, is the measure of the initial velocity of the ball.

21. To deduce the graduation of the oblique ascent from that of the vertical descent, we again draw the triangle A B G exactly the same in all respects as that in Fig. 3343; but we now add a line A Y, parallel to and equal to B G, and we join B Y, so that A G B Y in Fig. 3344 is a parallelogram, of which A B is the diagonal, and in which we know the magnitude of every line.

3344.



22. The line A Y now added represents the vertical ascent of the ball during the time of flight; this line and the line B G are added for the purpose of bringing the question within the scope of the law of the composition and resolution of forces.

23. That law teaches us that the force which produces the motion represented by the diagonal A B, is the resultant or equivalent of two forces producing motions represented both in magnitude and direction by the two sides A Y, A G, of the parallelogram, of which A B is the diagonal.

24. If therefore we could determine the graduation for time of the line A Y, we could at once find that of A B; and we could then, to use Colonel Boxer's words once more, "compound the motion produced by gravity with the motion in the line" of direction, "in order to obtain the actual motion of the shot."

25. We desire to determine the graduation of A Y, and we know that it is equal in magnitude to B G; it is 9981 ft.; the duration of the motion which it represents is the same as in B G, 27·1 seconds of time, and still it is quite certain that the graduation of A Y cannot be that of B G read in inverse order of succession.

26. The graduation of B G is the same for any one number of seconds of time of flight, whatever be the elevation, as it is the fall by gravity in the time of flight *t*; the graduation of this line is always an increasing series or progression, it must always commence in the same manner; if the time of flight is four seconds, the graduation of the descent will always be 1, 3, 5, 7, total 16 spaces of $\frac{1}{2} g$, whether the elevation be 5° or 85°.

27. But the graduation of A Y varies with every change of elevation; the motion represented by this line is necessarily exactly equal in magnitude and in duration to the motion represented by the parallel B G, but it will always be differently graduated; in four seconds' time of flight the ascent will always be 16 spaces, but they will be divided into 7, 5, 3, 1, total 16, for elevation 89° 59′ 58″; and into 4, 4, 4, 4, total 16, for elevation 0° 00′ 02″.

28. At elevation 90° the oblique ascent and the vertical ascent become merged in one, and, as we have just seen, the graduation is the inverted reading of the descent; we are therefore enabled to determine its graduation by referring to the Table described in our paragraph 19, which we shall suppose to be in the hands of our reader.

29. We now return to our selected example, the range 9981 ft. at elevation 45°; we showed in paragraph 14 that the oblique ascent was 14115·26 ft., the simultaneous vertical descent 9981 ft.

30. If we now change the elevation from 45° to 90°, the ascent in 27·1 seconds will again be equal to 14.115 ft., the descent again 9981 ft., therefore at the expiration of 27·1 seconds of time the ball will be at a height of 4134·26 ft. vertically over the point A from which it was projected.

31. To enable this ball to reach the ground, addition must be made to the time, and as the ascent and descent are simultaneous motions, additions to the time of either bring equal addition to the time of the other.

32. But equal addition to the time by no means brings equal addition to the magnitude; the addition of one second will bring an increase of 16 ft. to the ascent and of 671 ft. to the descent; a very few such additions will bring the two to equality of magnitude, and we proceed to try how many will do it.

33. We try an addition of 6·9 seconds, making the time of flight 27·1 + 6·9 = 34 seconds,
then we find in our Table that $34^2 \times 12{\cdot}9 =$ 14912·4
We also find that $6{\cdot}9^2 \times 15{\cdot}61 =$ 743·1921
which we add to the ascent, 14115·26

making the ascent 14858·4521 = 14858·4521

so that the descent now exceeds the ascent by 53·9479 ft., and we must try a less addition.

34. We try an addition of 6·8 seconds, making the time of flight 27·1 + 6·8 = 33·9 seconds,
and we find in our Table that $33{\cdot}9^2 \times 12{\cdot}91 =$ 14836·3011
We also find that $6{\cdot}8^2 \times 15{\cdot}62 =$ 722·2688
which we add to the ascent 14115·26

making the whole ascent 14837·5288 = 14837·5288

the ascent now exceeds the descent by 1·2277 ft., but we are satisfied.

35. The fall in 34 seconds we have seen to be 14912·4
and " 33·9 " " 14836·3011

the differences 0·1 second of time and 76·0989 ft. indicate a velocity of 760·989, say 761 ft. a second.

36. Therefore the initial velocity of the ball, which at 45° elevation ranged 3327 yds., was 761 ft. a second.

37. We can now give the graduation of the ascent from our Table; we read in it that the fall in

29·9 seconds is $29\cdot9^2 \times 13\cdot31 = 11899\cdot2731$ difference 713·767
30·9 „ $30\cdot9^2 \times 13\cdot21 = 12613\cdot0401$ „ 727·827
31·9 „ $31\cdot9^2 \times 13\cdot11 = 13340\cdot8671$ „ 741·287
32·9 „ $32\cdot9^2 \times 13\cdot01 = 14082\cdot1541$ „ 754·147
33·9 „ $33\cdot9^2 \times 12\cdot91 = 14836\cdot3011$

38. The inverted reading of this Table is the graduation of the ascent; it commences thus, in

	Cumulative.	Gradual.						
1 second	754·147	754·147						
2 seconds	1495·434	741·287	1st difference	12·86				
3 „	2223·261	727·827	„	13·46	2nd difference	0·6		
4 „	2937·028	713·767	„	14·06	„	0·6	3rd difference	0·0
5 „	3636·135	699·107	„	14·66	„	0·6	„	0·0

39. We give, Table A, the graduation of the ascent for even seconds of time, for initial velocity 761 ft. a second, and the simultaneous descent; we also give thirty-three different ranges, together with the angles of elevation, by the use of which these ranges would be obtained.

40. In any right-angled triangle whatever, if the reader will mark off upon the hypothenuse the distances given as ascents, and let fall perpendiculars to denote the fall by gravity, then a line joining the lower extremities of all these perpendiculars is the trajectory, which we said in paragraph 3 we could draw without any difficulty.

41. In the Aide Mémoire a l'usage des Officiers d'Artillerie, p. 431, we find a Table containing thirty different ranges for elevation 45°, with the initial velocity for each, but not the time of flight.

42. The second of these ranges is 3261 mètres, its initial velocity 239 mètres; reducing these to English measures, we have 10,699 ft. of range, with 784·136 ft. velocity.

43. Here the oblique ascent is $10699\sqrt{2} = 15130\cdot7$, and the vertical descent, or fall by gravity, is 10,699 ft., which indicates a time of flight of 28·17 seconds for $28\cdot17^2 \times 13\cdot483 = 10699\cdot4198187$.

44. An ascent of 15130·7 ft. in 28·17 seconds is what we have to graduate; we find that a descent of 35·32 seconds will be as follows, namely;—

$35\cdot32^2 \times 12\cdot768 = 15928\cdot1106432$ ft., the time being 28·17,
subtract and add 28·17 2·817

the differences $7\cdot15^2 \times 15\cdot585 = 796\cdot7430625$

show a fall in 28·17 seconds of 15131·3675807 ft.,

which is only 8 in. in excess of the ascent.

45. The velocity acquired by a fall of this duration is thus found;—

from $35\cdot32^2 \times 12\cdot768 = 15928\cdot1106432$
deduct $35\cdot31^2 \times 12\cdot769 = 15920\cdot3394009$

the differences being − 0·01, 0·001, and 7·7712423,

indicate a velocity of 777·124 ft. a second, to compare with 784·136 ft. a second, as given in the Aide Mémoire.

46. As no book in the English language gives us any record of initial velocity for range and elevation, we give, in Table B, thirty ranges for 45° elevation, with the time of flight calculated, and the initial velocity deduced; and in the same page, for convenience of comparison, we give Table C, named in paragraph 41.

47. We give, Fig. 3345, a drawing of a very simple instrument, by which, when made to a larger scale, any rifleman may at once draw the trajectory of his bullet, and read off its initial velocity, and the angle of its descent.

48. For instance, suppose a ball fired at elevation 5°, its range measured is 1000 yds. exactly. Then the range being 3000 ft., the oblique ascent is 3011·4 ft., the vertical descent or fall by gravity is 262·466 ft., therefore the time of flight is 4·06 seconds, very nearly.

49. Dividing the oblique ascent by the time of flight, we have $\frac{3011\cdot4}{4\cdot06} = 741\cdot7$ ft. a second, the mean velocity of the ascent. The Table described in our paragraph 19, of which the instrument described in paragraph 47 and shown in Fig. 3345 is a portable epitome, shows that a velocity of 741·7 ft. is the result of a fall of 32·85 seconds;

to this we add half the time of flight 2·5 seconds,

and the sum of the two, 35·35 seconds, is the time of flight for this velocity at 90° elevation; the Table shows us that the velocity would be 777 ft. a second, roughly.

50. For all elevations usually employed with rifles or field artillery, the instrument shown in Fig. 3345 would enable the student to draw the trajectory at once; supposing his instrument to be made on a sufficiently large scale, he lays the mean velocity of the ascent, as found by dividing its magnitude by the time of flight, exactly against the centre of the hypothenuse of the triangle, calculated in paragraph 48, and marks off all the fifty spaces, twenty-five on each side, which will form the graduation of the hypothenuse, lets fall forty-nine perpendiculars to denote the fall by gravity, and joins the fifty points by a curve line, which is the true trajectory to the tenths of seconds of time.

51. But the instrument will not serve for any velocities beyond 800 ft. a second, because, as said in paragraph 4, we have not the data, and private experiments are not authoritative.

52. The want of such an instrument is very strikingly shown by an error contained in the clever little Text-Book for officers, sent to the Schools of Musketry, published by authority.

53. We read, in p. 8, that it was found in France that the range of the common percussion musket, with the regulation charge, at an angle of from 4° to 5°, was 640 yds., or 1920 ft., and that the usual velocity was "some 500 yds. per second," or, in our usual mode of expressing it, 1500 ft. per second.

54. We shall show how far from correct this is. Taking the elevation as 4°, then we multiply the range by the tangent of the elevation, 1920 × tan. 4° = 134·26 ft., for the fall by gravity in the time of flight, which is therefore 2·9 seconds ($2{\cdot}896^2 \times 16{\cdot}0104 = 134{\cdot}276$) as the time of flight, and we find the oblique ascent, 1920 × secant 4° = 1924·7 ft.

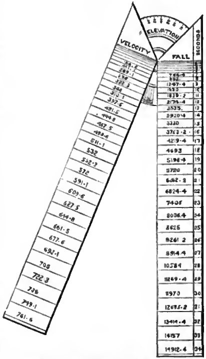
55. Dividing the oblique ascent by the time of flight, we have 663·7 ft. a second as the mean velocity of the ascent.

56. Our instrument is only graduated for seconds, as shown in Fig. 3345, but the Table quoted in paragraphs 18 and 19 shows how it would be read if graduated to the tenth parts of seconds, which we shall suppose to be done.

57. We find that a fall of 27·15 seconds would give a velocity of 663·9 ft. a second, then if we add half the time of flight, $\frac{2{\cdot}9}{2} = 1{\cdot}45$, to the time for the mean velocity, 27·15 seconds, we have 28·6 seconds as the time for the initial velocity, and the difference between the same two is the time for the final velocity, 25·7 seconds.

58. Our Table D shows us that the velocity for 28·6 seconds is 687 ft., that for 25·7 seconds is 639·67 ft. a second; these contrast strongly with the 1500 ft. velocity quoted by the Text-Book from the French.

3345.



Instrument to facilitate the drawing of the trajectory of any ball at any elevation with any velocity.

Table A.—Ascent, Descent, Ranges, and Elevations for Initial Velocity, 761 feet a second.

Seconds of Time.	Ascent.				Descent.	Range.	Elevation.
	Cumulative.	Gradual.	Differences.				
	feet.	feet.	feet.		feet.	feet.	° ′ ″
1	754·147	754·147	..	0·6	16·2	754·0	1 13 51
2	1495·434	741·287	12·86		64·4	1494·0	2 28 5
3	2223·261	727·827	13·46		144·0	2218·6	3 42 47
4	2937·028	713·767	14·06		254·4	2926·0	4 58 9
5	3636·135	699·107	14·66		395·0	3614·6	6 14 11
6	4319·982	683·817	15·26		565·2	4282·8	7 31 4
7	4987·969	667·987	15·86		764·4	4929·0	8 48 55
8	5639·496	651·527	16·46		992·0	5551·5	10 7 52
9	6273·963	631·467	17·06		1247·4	6229·5	11 28 4
10	6890·77	616·807	17·66		1530·0	6718·7	12 49 43
11	7489·317	598·547	18·26		1839·2	7260·0	14 12 55
12	8069·004	579·687	18·86		2174·4	7770·5	15 37 59
13	8629·231	560·227	19·46		2535·0	8248·5	17 5 1
14	9169·398	540·167	20·06		2920·4	8692·0	18 34 19
15	9688·905	519·507	20·66		3330·0	9098·6	20 6 7
16	10187·152	498·247	21·26		3763·2	9466·6	21 40 44

TABLE A—*continued.*

Seconds of Time.	Ascent.				Descent.	Range.	Elevation.
	Cumulative.	Gradual.	Differences.				
	feet.	feet.	feet.		feet.	feet.	° ′ ″
17	10663·539	476·387	21·86	0·6	4219·4	9793·3	23 18 31
18	11117·466	453·927	22·46		4698·0	10076·0	24 59 50
19	11548·333	430·867	23·06		5198·4	10312·2	26 44 46
20	11955·54	407·207	23·66		5720·0	10498·4	28 35 0
21	12338·487	382·917	24·26		6262·2	10631·2	30 29 0
22	12696·574	358·087	24·86		6824·4	10706·5	32 30 49
23	13029·201	332·627	25·46		7406·0	10719·7	34 38 23
24	13335·768	300·567	26·06		8006·4	10664·9	36 53 47
25	13615·675	279·907	26·66		8625·0	10535·4	39 18 21
26	13868·322	252·647	27·26		9261·2	10322·8	41 53 50
27	14093·109	224·787	27·86		9914·4	10016·0	44 42 28
28	14289·436	196·327	28·46		10584·0	9600·	47 47 24
29	14456·703	167·267	29·06		11269·4	9055·0	51 13 2
30	14594·31	137·607	29·66		11970·0	8349·4	55 0 11
31	14701·657	107·347	30·26		12685·2	7431·3	59 38 14
32	14778·144	76·487	30·86		13414·4	6200·0	65 11 31
33	14823·171	45·027	31·46		14157·0	4393·8	72 45 27
33·9	14836·3011	12·967	32·06		14836·3	0·0	90 0 0

TABLE B.—RANGES AT 45° ELEVATION, WITH THE TIMES OF FLIGHT DEDUCED, AND THE INITIAL VELOCITY DETERMINED.

Range and Fall.		Time of Flight.	Oblique Ascent.	Unexpired Time of Ascent.	Time of Flight at Elevation 90°.	Vertical Ascent.	Initial Velocity.
yards.	feet.						
100	300	4·3485	424·26	0·903	5·253	435·29	162·87
200	600	6·2	848·53	1·31	7·51	876·96	228·0
300	900	7·61	1272·79	1·64	9·25	1316·52	275·8
400	1200	8·82	1697·00	1·93	10·75	1759·54	315·2
500	1500	9·9	2121·32	2·16	12·06	2195·33	350·0
600	1800	10·88	2545·58	2·39	13·27	2636·64	379·0
700	2100	11·785	2969·84	2·615	14·4	3081·37	407·0
800	2400	12·635	3394·11	2·815	15·45	3522·05	432·0
900	2700	13·436	3818·37	3·004	10·44	3961·13	454·8
1000	3000	14·21	5242·63	3·19	17·4	4408·19	476·4
1100	3300	14·93	4666·89	3·37	18·3	4845·86	496·0
1200	3600	15·63	5091·16	3·53	19·16	5280·45	514·3
1300	3900	16·305	5515·42	3·725	20·03	5736·0	532·7
1400	4200	16·96	5939·68	3·9	20·86	6185·0	550·0
1500	4500	17·59	6363·96	4·06	21·65	6625·39	565·0
1600	4800	18·207	6788·22	4·22	22·427	7070·4	580·0
1700	5100	18·81	7212·48	4·38	23·19	7518·65	595·0
1800	5400	19·39	7636·75	4·53	23·92	7957·79	608·0
1900	5700	19·964	8061·01	4·7	24·664	8412·0	621·0
2000	6000	20·521	8485·28	4·88	25·41	8883·0	634·0
2100	6300	21·0695	8909·55	5·0	26·0695	9209·32	646·0
2200	6600	21·605	9333·81	5·15	26·75	9749·54	657·3
2300	6900	22·13	9758·07	5·3	27·43	10200·35	668·5
2400	7200	22·65	10182·33	5·45	28·1	10651·84	679·0
2500	7500	23·16	10606·6	5·6	28·76	11103·48	689·5
2600	7800	23·66	11030·86	5·74	29·4	11517·85	700·0
2700	8100	21·15	11455·13	5·9	30·05	12005·42	708·7
2800	8400	24·64	11879·39	6·04	30·68	12154·79	717·6
2900	8700	25·12	12303·66	6·18	31·3	12902·52	726·4
3000	9000	25·593	12727·92	8·331	31·93	13362·91	735·0
3100	9300	26·06	13152·18	6·48	32·54	13813·77	743·0
3200	9600	26·521	13576·44	6·019	33·14	14262·0	751·0
3300	9900	26·979	14000·71	6·761	33·74	14711·8	758·2
3327	9981	27·1	14115·76	6·8	33·9	14836·3	761·0

TABLE C.—RANGES AT 45° ELEVATION, WITH THE TIMES OF FLIGHT DEDUCED, WITH THE INITIAL VELOCITIES DETERMINED BY M. LOMBARD.

From the Aide Mémoire a l'usage des Officiers d'Artillerie, p. 431.
Reduced to English Measures.

Velocity.	Range.	Time.	Velocity.	Range.	Time.	Velocity.	Range.	Time.
892·4	12431·34	30·65	679·15	8787·26	25·26	439·64	4252·05	17·06
784·14	10699·0	28·16	606·97	7565·76	23·26	364·18	3625·4	15·69
695·55	9225·9	25·95	544·63	6483·07	21·4	354·34	3064·36	14·35
623·87	7949·6	23·9	488·85	5538·17	19·65	318·25	2552·54	13·05
557·75	6807·9	21·96	439·64	4675·29	17·95	282·16	2103·06	11·8
501·98	5813·76	20·175	393·71	3891·15	16·28	249·35	1692·95	10·54
449·48	4911·5	18·43	347·78	3202·16	14·7	216·54	1328·77	9·3
400·27	4084·7	16·7	308·41	3238·25	14·78	285·44	1010·52	8·03
357·62	3369·5	15·1	269·03	2027·6	11·58	..	..	..
314·97	2710·0	13·46	229·66	1542·02	10·04	..	..	..
275·6	2129·3	11·86	..	..	..	..	..	..
226·26	1617·5	10·3	..	..	..	..	..	..

TABLE D.—THE FALL BY GRAVITY AS MODIFIED BY THE RESISTANCE OF THE ATMOSPHERE.

The square of the time of falling × by the substitute for 16 1/12.		Fall by gravity in the whole time.	Fall in each tenth of a second.	Velocity acquired.	The square of the time of falling × by the substitute for 16 1/12.		Fall by gravity in the whole time.	Fall in each tenth of a second.	Velocity acquired.
$0·1^2$ ×	16·29	0·1629	0·4883	3·756	$4·6^2$ ×	15·84	335·1744	11·5103	143·611
2	8	0·6512	·8131	7·007	7	3	49·6847	·8081	6·592
3	7	1·4643	1·1373	10·252	8	2	64·4928	15·1053	9·467
4	6	2·6016	·4609	13·491	9	1	79·5981	·4019	152·536
5	5	4·0625	·7839	16·724	5·0	·80	95·	·6979	5·5
6	4	5·8464	2·1063	19·951	1	·79	410·6979	·9933	8·456
7	3	7·9527	·4281	22·172	2	8	26·6912	16·2881	161·407
8	2	10·3808	·7493	25·387	3	7	42·9793	·5823	4·352
9	1	13·1301	3·0699	28·596	4	6	59·5616	·8759	7·291
1·0	·20	16·2	·3899	31·8	5	5	76·4375	17·1689	170·224
1	·19	19·5899	·7093	34·996	6	4	93·6064	·4613	8·151
2	8	23·2992	4·0281	38·187	7	3	511·0677	·7531	6·072
3	7	27·3273	·3463	41·372	8	2	28·8208	18·0443	8·987
4	6	31·6736	·6639	44·551	9	1	46·8651	·3349	181·896
5	5	36·3375	·9809	47·724	6·0	·70	65·2	·6249	4·8
6	4	41·3184	5·2973	50·892	1	·69	83·8249	·9143	7·696
7	3	46·6157	·6131	54·052	2	8	602·7392	19·2031	190·587
8	2	52·2288	·9283	57·207	3	7	21·9423	·4913	3·472
9	1	58·1571	6·2429	60·956	4	6	41·4336	·7789	6·351
2·0	·10	64·4	·5569	64·1	5	5	61·2125	20·0659	9·224
1	·09	70·9569	·8703	67·236	6	4	81·2784	·3523	202·091
2	·08	77·8272	7·1831	70·367	7	3	701·6307	·6381	4·952
3	·07	85·0103	·4953	73·492	8	2	22·2688	·9233	7·807
4	·06	92·5056	·8069	76·611	9	1	43·1921	21·2079	210·656
5	·05	100·3125	8·1179	79·724	7·0	·60	64·4	·4919	3·5
6	·01	108·4304	·4283	82·831	1	·59	85·8919	·7753	6·336
7	·03	116·8587	·7381	85·932	2	8	807·6672	22·0581	9·167
8	·02	125·5968	9·0473	88·927	3	7	29·7253	·3403	221·992
9	·01	134·6441	·3559	92·016	4	6	52·0656	·6219	4·811
3·0	·00	144·	·6639	95·1	5	5	74·6875	·9029	7·624
1^2 ×	15·99	153·6639	·9713	8·176	6	4	97·5904	23·1833	230·431
2	8	163·6352	10·2781	101·247	7	3	920·7737	·4631	3·232
3	7	173·9133	·5843	4·312	8	2	44·2368	·7423	6·027
4	6	184·4976	·8899	7·371	9	1	67·9791	24·0209	8·816
5	5	195·3875	11·1949	110·424	8·0	·50	92·	·2989	241·6
6	4	206·5824	·4993	3·471	1	·49	1016·2989	·5763	4·376
7	3	18·0817	·8031	6·512	2	8	40·8752	·8531	7·147
8	2	29·8848	12·1063	9·547	3	7	65·7283	25·1293	9·912
9	1	41·9911	·4089	122·576	4	6	90·8576	·4049	252·671
4·0	·90	54·4	·7109	5·6	5	5	1116·2625	·6799	5·424
1	·89	67·1109	13·0123	8·616	6	4	41·9424	·9543	8·171
2	8	80·1232	·3131	131·627	7	3	67·8967	26·2281	260·912
3	7	93·4363	·6133	4·632	8	2	94·1248	·5013	3·647
4	6	307·0496	·9129	7·631	9	1	1220·6261	·7739	6·376
5	5	20·9625	14·2119	140·624	9·0	·40	47·4	27·0459	9·1

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TABLE D—*continued.*

$T^2 \times g^1$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.	$T^2 \times g^1$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.
9·1^2 ×	15·39	1274·4459	27·3173	271·816	16·1^2 ×	14·69	3807·7949	44·8243	447·096
2	8	1301·7632	·5881	4·527	2	8	52·6192	45·0531	9·387
3	7	29·3513	·8583	7·232	3	7	97·6723	·2813	451·672
4	6	57·2096	28·1279	9·931	4	6	3942·9536	·5089	3·951
5	5	85·3375	·3969	282·624	5	5	88·4625	·7359	6·224
6	4	1413·7344	·6658	5·311	6	4	4034·7984	·9623	8·491
7	3	42·3997	·9331	7·992	7	3	80·1607	46·1881	460·752
8	2	71·3328	29·2003	290·667	8	2	4126·3488	·4133	3·007
9	1	1500·5331	·4669	3·336	9	1	72·7621	·6379	5·256
10·0	·30	30·	·7329	6·	17·0	·60	4219·4	·8619	7·5
1	·29	59·7329	·9983	8·656	1	·59	66·2619	47·0853	9·736
2	8	89·7312	30·2631	301·307	2	8	4313·3472	·3081	471·967
3	7	1619·9943	·5273	3·952	3	7	60·6553	·5303	4·192
4	6	50·5216	·7907	6·591	4	6	4408·1836	·7519	6·411
5	5	81·3125	31·0539	9·224	5	5	55·9375	·9729	8·624
6	4	1712·3664	·3163	311·851	6	4	4503·9104	48·1933	480·831
7	3	43·6827	·5781	4·472	7	3	52·1037	·4131	3·032
8	2	75·2608	·8393	7·027	8	2	4600·5168	·6323	5·227
9	1	1807·1001	32·0999	9·696	9	1	49·1491	·8509	7·416
11·0	·20	39·2	·3599	322·3	18·0	·50	98·	49·0689	9·6
1	·19	71·5599	·6193	4·896	1	·49	4747·0689	·2863	491·776
2	8	1904·1792	·8781	7·487	2	8	96·3552	·5031	3·947
3	7	87·0573	33·1363	330·072	3	7	4845·8583	·7193	6·112
4	6	70·1936	·3939	2·651	4	6	95·5776	·9349	8·271
5	5	2003·5875	·6509	5·224	5	5	4945·5125	50·1499	500·424
6	4	87·2384	·9073	7·791	6	4	95·6624	·3643	2·571
7	3	71·1457	34·1631	340·352	7	3	5045·0267	·5781	4·712
8	2	2105·3088	·4183	2·907	8	2	095·6048	·7913	6·847
9	1	39·7271	·6729	5·456	9	1	146·3961	51·0039	8·976
12·0	·10	74·4	·9269	8·	19·0	·40	198·4	·2159	511·1
1	·09	2209·3269	35·1803	350·536	1	·39	249·6159	·4273	3·216
2	8	44·5072	·4331	3·067	2	8	301·0432	·6381	5·327
3	7	79·9403	·6853	5·592	3	7	352·6813	·8483	7·432
4	6	2315·6256	·9369	8·111	4	6	404·5296	52·0579	9·531
5	5	51·5625	36·1879	360·624	5	5	456·5875	·2669	521·624
6	4	87·7504	·4383	3·131	6	4	508·8544	·4753	3·711
7	3	2424·1887	·6881	5·632	7	3	561·3297	·6831	5·792
8	2	60·8768	·9373	8·127	8	2	614·0128	·8903	7·867
9	1	97·8141	37·1859	370·616	9	1	666·9031	53·0969	9·936
13·0	·00	2535·	·4339	3·1	20·0	·30	720·	·3029	532·
1^2 ×	14·99	72·4339	·6813	5·576	1	·29	773·3029	·5083	4·056
2	8	2610·1152	·9281	8·047	2	8	826·8112	·7131	6·107
3	7	48·0433	38·1743	380·512	3	7	880·5243	·9173	8·152
4	6	86·2176	·4199	2·971	4	6	934·4416	54·1209	540·191
5	5	2724·6375	·6649	5·424	5	5	988·5625	·3239	2·224
6	4	63·3024	·9098	7·871	6	4	6042·8864	·5263	4·251
7	3	2802·2177	39·1531	390·312	7	3	097·4127	·7281	6·272
8	2	41·3648	·3963	2·747	8	2	162·1408	·9298	8·287
9	1	80·7611	·6389	5·176	9	1	207·0701	55·1299	550·296
14·0	·90	2920·4	·8809	7·6	21·0	·20	262·2	·3399	2·3
1	·89	60·2809	40·1223	400·016	1	·19	317·5299	·5293	4·296
2	8	3000·4032	·3631	2·427	2	8	373·0592	·7281	6·287
3	7	40·7663	·6033	4·832	3	7	428·7873	·9263	8·272
4	6	81·3696	·7429	7·231	4	6	484·7136	56·1239	560·251
5	5	3122·2125	·9819	9·624	5	5	540·8375	·3209	2·224
6	4	63·2944	41·3203	412·011	6	4	597·1584	·5173	4·191
7	3	3204·6147	·5581	4·392	7	3	653·6757	·7131	6·152
8	2	46·1728	·7953	6·767	8	2	710·3888	·9083	8·107
9	1	87·9681	42·0319	9·136	9	1	767·2971	57·1029	570·056
15·0	·80	3330·	·2679	421·5	22·0	·10	824·4	·2969	2·
1	·79	72·2679	·5003	3·856	1	·09	881·6969	·4903	3·936
2	8	3414·7712	·7381	6·207	2	8	939·1872	·6831	5·867
3	7	57·5093	·9723	8·552	3	7	996·8703	·8753	7·792
4	6	3500·4816	43·2059	430·891	4	6	7054·7456	58·0669	9·711
5	5	43·6875	·4389	3·224	5	5	112·8125	·2579	581·624
6	4	87·1264	·6713	5·551	6	4	171·0704	·4483	3·531
7	3	3630·7977	·9031	7·872	7	3	229·5187	·6381	5·432
8	2	74·7008	44·1343	440·187	8	2	288·1568	·8273	7·327
9	1	3718·8351	·3649	2·496	9	1	346·9841	59·0159	9·216
16·0	·70	63·2	·5949	4·8	23·0	·00	406·	·2039	591·1

Table D—*continued*.

$T^2 \times g^1$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.	$T^2 \times g^1$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.
$23·1^2$ ×	13·99	7465·2039	59·3913	592·976	$30·1^2$ ×	13·29	12040·8729	71·0183	709·456
2	8	524·5952	·5781	4·847	2	8	111·8912	·1631	710·907
3	7	584·1733	·7643	6·712	3	7	183·0543	·3073	2·352
4	6	643·9376	·9499	8·571	4	6	254·3616	·4509	3·791
5	5	703·8875	60·1319	600·424	5	5	325·8125	·5939	5·224
6	4	764·0224	·3193	2·271	6	4	397·4064	·7363	6·651
7	3	824·3417	·5031	4·112	7	3	469·1427	·8781	8·072
8	2	884·8448	·6863	5·947	8	2	541·0208	72·0193	9·487
9	1	945·5311	·8689	7·776	9	1	613·0401	·1599	720·896
24·0	·90	8006·4	61·0509	9·6	31·0	·20	685·2	·2999	2·3
1	·89	067·4509	·2323	611·416	1	·19	757·4999	·4393	3·696
2	8	128·6832	·4131	3·227	2	8	829·9392	·5781	5·087
3	7	190·0963	·5933	5·032	3	7	902·5173	·7163	6·472
4	6	251·6896	·7729	6·831	4	6	975·2336	·8539	7·851
5	5	313·4625	·9519	8·624	5	5	13018·0875	·9909	9·224
6	4	375·4141	62·1302	620·411	6	4	121·0784	73·1273	730·591
7	3	437·5447	·3081	2·192	7	3	194·2057	·2631	1·952
8	2	499·8528	·4853	3·967	8	2	267·4688	·3983	3·307
9	1	562·3381	·6619	5·736	9	1	340·8671	·5329	4·656
25·0	·80	625·	·8379	7·5	32·0	·10	414·4	·6669	6·
1	·79	687·8379	63·0133	9·256	1	·09	488·0669	·8003	7·336
2	8	750·8512	·1881	631·007	2	8	561·8672	·9331	8·667
3	7	814·0393	·3623	2·752	3	7	635·8003	74·0653	9·992
4	6	877·4016	·5359	4·491	4	6	709·8656	·1969	741·311
5	5	940·9375	·7089	6·224	5	5	784·0625	·3279	2·624
6	4	9004·6164	·8813	7·951	6	4	858·3904	·4583	3·931
7	3	068·5277	64·0531	9·672	7	3	932·8487	·5881	5·232
8	2	132·5808	·2243	641·387	8	2	14007·4368	·7173	6·527
9	1	196·8061	·3949	3·096	9	1	082·1541	·8459	7·816
26·0	·70	261·2	·5649	4·8	33·0	·00	157·	·9739	9·1
1	·69	325·7649	·7343	6·496	1^2 ×	12·99	231·9739	75·1013	750·376
2	8	390·4992	·9031	8·187	2	8	307·0752	·2281	1·647
3	7	455·4023	65·0713	9·872	3	7	382·3033	·3543	2·912
4	6	520·4736	·2389	651·551	4	6	457·6576	·4799	4·171
5	5	585·7125	·4059	3·224	5	5	533·1375	·6049	5·424
6	4	651·1184	·5723	4·891	6	4	608·7424	·7293	6·671
7	3	716·6907	·7381	6·552	7	3	684·4717	·8581	7·912
8	2	782·4288	·9033	8·207	8	2	760·3248	·9763	9·147
9	1	848·3321	66·0679	9·856	9	1	836·3011	76·0989	760·376
27·0	·60	914·4	·2319	661·5	34·0	·90	912·4	·2209	1·6
1	·59	980·6319	·3953	3·136	1	·89	980·6209	·3423	2·816
2	8	10047·0272	·5581	4·767	2	8	15064·9632	·4631	4·027
3	7	113·5858	·7203	6·392	3	7	141·4263	·5833	5·232
4	6	180·3056	·8819	8·011	4	6	218·0096	·7029	6·431
5	5	247·1875	67·0429	9·624	5	5	294·7125	·8219	7·624
6	4	314·2304	·2033	671·231	6	4	371·5344	·9403	8·811
7	3	381·4337	·3631	2·832	7	3	448·4747	77·0581	9·992
8	2	448·7968	·5223	4·427	8	2	525·5328	·1753	771·167
9	1	516·3191	·6809	6·016	9	1	602·7081	·2919	2·336
28·0	·50	584·	·8389	7·6	35·0	·80	680·	·4079	3·5
1	·49	651·8389	·9963	9·176	1	·79	757·4079	·5233	4·656
2	8	719·8352	68·1531	680·747	2	8	834·9312	·6381	5·807
3	7	787·9883	·3093	2·312	3	7	912·5693	·7523	6·952
4	6	856·2976	·4649	3·871	4	6	990·3216	·8659	8·091
5	5	924·7625	·6199	5·424	5	5	16068·1875	·9789	9·224
6	4	993·3824	·7743	6·971	6	4	146·1664	78·0913	780·351
7	3	11062·1567	·9281	8·512	7	3	224·2577	·2031	1·472
8	2	131·0848	69·0813	690·047	8	2	302·4608	·3143	2·587
9	1	200·1661	·2339	1·576	9	1	380·7751	·4249	3·696
29·0	·40	269·4	·3859	3·1	36·0	·70	459·2	·5349	4·8
1	·39	338·7859	·5373	4·616	1	·69	537·7349	·6443	5·896
2	8	408·3232	·6881	6·127	2	8	616·3792	·7531	6·987
3	7	478·0113	·8383	7·632	3	7	695·1323	·8613	8·072
4	6	547·8496	·9879	9·131	4	6	773·9936	·9689	9·151
5	5	617·8375	70·1369	700·624	5	5	852·9625	79·0759	790·224
6	4	687·9744	·2853	2·111	6	4	932·0384	·1823	1·291
7	3	758·2597	·4331	3·592	7	3	17011·2207	·2881	2·352
8	2	828·6928	·5803	5·067	8	2	090·5088	·3933	3·407
9	1	899·2731	·7269	6·586	9	1	169·9021	·4979	4·456
30·0	·30	970·	·8729	8·	37·0	·60	249·4	·6019	5·5

TABLE D—*continued.*

$T^2 \times g^1$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.
$37\cdot1^2 \times$	12·59	17329·0019	79·7053	796·536
2	8	408·7072	·8081	7·567
3	7	488·5153	·9103	8·592
4	6	568·4256	80·0119	9·611
5	5	648·4735	·1129	800·624
6	4	728·5504	·2133	1·631
7	3	808·7637	·3131	2·632
8	2	889·0768	·4123	3·626
9	1	969·4891	·5109	4·616
38·0	·50	18050·	·6089	5·6
1	·49	130·6089	·7063	6·576
2	8	211·3152	·8031	7·547
3	7	292·1183	·8993	8·512
4	6	373·0176	·9949	9·471
5	5	454·0125	81·0899	810·424
6	4	525·1024	·1843	1·371
7	3	616·2867	·2781	2·312
8	2	697·5648	·3713	3·247
9	1	778·9361	·4639	4·176
39·0	·40	860·4	·5559	5·1
1	·39	941·9559	·6473	6·016
2	8	19023·6032	·7381	6·927
3	7	105·3413	·8283	7·832
4	6	187·1696	·9179	8·731
5	5	269·0875	82·0069	9·624
6	4	351·0944	·0953	820·511
7	3	433·1897	·1831	1·392
8	2	515·3728	·2703	2·267
9	1	597·6481	·3569	3·136
40·0	·30	680·	·4429	4·
1	·29	762·4429	·5283	4·856
2	8	814·9712	·6131	5·707
3	7	927·5843	·6973	6·552
4	6	20010·2816	·7809	7·391
5	5	093·0625	·8639	8·224
6	4	175·9264	·9463	9·051
7	3	258·8727	83·0281	9·872
8	2	341·9008	·1093	830·687
9	1	425·8101	·1899	1·496
41·0	·20	508·2	·2699	2·3
1	·19	591·4699	·3493	3·096
2	8	674·8192	·4281	3·887
3	7	758·2473	·5063	4·672
4	6	841·7536	·5839	5·451
5	5	925·3375	·6609	6·224
6	4	21008·9984	·7373	6·991
7	8	092·7357	·8131	7·752
8	2	176·5488	·8883	8·507
9	1	260·4371	·9629	9·256
42·0	·10	344·4	84·0369	840·
1	·09	428·4369	·1103	0·736
2	8	512·5472	·1831	1·467
3	7	596·7303	·2553	2·192
4	6	680·9856	·3629	2·911
5	5	765·3125	·3979	3·624
6	4	849·7104	·4683	4·331
7	3	934·1789	·5381	5·032
8	2	22018·7168	·6073	5·727
9	1	103·3241	·6759	6·416
43·0	·00	188·		7·1
$\cdot1^2 \times$	11·99	272·7439	·8113	7·776
2	8	357·5552	·8781	8·447
3	7	442·4333	·9443	9·112
4	6	527·3776	85·0099	9·771
5	5	612·3875	·0749	850·424
6	4	697·4624	·1393	1·011
7	3	782·6017	·2031	1·712
8	2	867·8048	·2663	2·347
9	1	953·0711	·3289	2·976
44·0	·90	23038·4	·3909	3·6
$44\cdot1^2 \times$	11·89	23123·7909	85·4523	854·216
2	8	209·2432	·5131	4·827
3	7	294·7563	·5733	5·432
4	6	380·3296	·6329	6·031
5	5	465·9625	·6919	6·624
6	4	551·6544	·7503	7·211
7	3	637·4047	·8081	7·792
8	2	723·2128	·8653	8·367
9	1	809·0781	·9219	8·936
45·0	·80	895·	·9779	9·5
1	·79	980·9779	86·0333	860·056
2	8	24067·0112	·0881	0·607
3	7	153·0993	·1423	1·152
4	6	239·2416	·1959	1·691
5	5	325·4375	·2489	2·224
6	4	411·6864	·3013	2·751
7	3	497·9877	·3531	3·272
8	2	584·3408	·4043	3·787
9	1	670·7451	·4549	4·296
46·0	·70	757·2	·5049	4·8
1	·69	843·7049	·5543	5·296
2	8	930·2592	·6031	5·787
3	7	25016·8623	·6513	6·272
4	6	103·5136	·6989	6·751
5	5	190·2125	·7459	7·224
6	4	276·9584	·7923	7·691
7	3	363·7507	·8381	8·152
8	2	450·5888	·8833	8·607
9	1	537·4721	·9279	9·056
47·0	·60	624·4	·9719	9·5
1	·59	711·3719	87·0153	9·936
2	8	798·3872	·0581	870·367
3	7	885·4453	·1003	0·792
4	6	972·5456	·1419	1·211
5	5	26059·6875	·1829	1·624
6	4	146·8704	·2233	2·031
7	3	234·0937	·2631	2·432
8	2	321·3568	·3023	2·827
9	1	408·6591	·3409	3·216
48·0	·50	496·	·3789	3·6
1	·49	583·3789	·4163	3·976
2	8	670·7952	·4531	4·347
3	7	758·2483	·4893	4·712
4	6	845·7376	·5249	5·011
5	5	933·2625	·5599	5·424
6	4	27020·8224	·5943	5·771
7	3	108·4167	·6281	6·112
8	2	196·0448	·6613	6·447
9	1	283·7061	·6939	6·776
49·0	·40	371·4	·7259	7·1
1	·39	459·1259	·7573	7·416
2	8	546·8832	·7881	7·727
3	7	634·6713	·8183	8·032
4	6	722·4896	·8179	8·331
5	5	810·3375	·8769	8·624
6	4	898·2144	·9053	8·911
7	3	986·1197	·9331	9·192
8	2	28074·0528	·9603	9·467
9	1	162·0131	·9869	9·736
50·0	·30	250·	88·0129	880·
1	·29	338·0129	·0383	0·256
2	8	426·0512	·0631	0·507
3	7	514·1143	·0873	0·752
4	6	602·2016	·1109	0·991
5	5	690·3125	·1339	1·224
6	4	778·4464	·1563	1·451
7	3	866·6027	·1781	1·672
8	2	954·7808	·1993	1·887
9	1	29042·9801	·2199	2·096
51·0	·20	181·2	·2399	2·3

TABLE D—*continued.*

$T^2 \times g'$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.	$T^2 \times g'$.		Fall in the whole time.	Fall in each tenth of a second.	Velocity acquired.
51·1² ×	11·19	29219·4399	88·2593	882·496	52·8² ×	11·02	30721·9968	88·4973	884·927
2	8	307·6992	·2781	2·687	9	1	810·4941	·5059	5·016
3	7	395·9773	·2963	2·872	53·0	·00	899·	·5139	5·1
4	6	484·2736	·3139	3·051	1² ×	10·99	987·5139	·5213	5·176
5	5	572·5875	·3309	3·224	2	8	31076·0352	·5281	5·247
6	4	660·9184	·3473	3·391	3	7	164·5633	·5343	5·312
7	3	749·2657	·3631	3·552	4	6	253·0976	·5399	5·371
8	2	837·6288	·3783	3·707	5	5	341·6375	·5449	5·424
9	1	926·0071	·2929	3·856	6	4	430·1824	·5493	5·471
52·0	·10	30014·4	·4069	4·	7	3	518·7317	·5531	5·512
1	·09	102·8069	·4203	4·136	8	2	607·2848	·5563	5·547
2	8	191·2272	·4331	4·267	9	1	695·8411	·5589	5·576
3	7	279·6603	·4453	4·392	54·0	·90	784·4	·5609	5·6
4	6	368·1056	·4569	4·511	1	·89	872·9609	·5623	5·616
5	5	456·5625	·4679	4·624	2	8	961·5232	·5631	5·627
6	4	545·0304	·4783	4·731	3	7	32050·0863	·5633	5·632
7	3	633·5087	·4881	4·832					

Gunnery is the science which enables us to determine the path of a shot through the air; it is the application of the laws of motion to the flight of military projectiles of every description; but at present Gen. Anstruther confines his attention to the flight of spherical bodies projected from smooth-bored cylinders; when this is well understood, it will be time enough to inquire what would result from using elongated shot or rifled barrels.

"If a body be projected (vertically) upwards, with the velocity it acquired in any time by descending freely, it will lose all its (upward) velocity in an equal time, and will (if not acted upon by gravity) ascend just to the same height from whence it fell, and will describe equal spaces in equal times, both in rising and falling, but in an inverse order; and it will have equal velocities at any one and the same point of the line described, both in ascending and descending."—Rutherford's Mathematics, 1841, p. 842.

These words, excepting those in parentheses, are Hutton's; those in parentheses are absolutely required to make the passage truth. For we know, from the second law of motion, that the force of gravity, acting upon this body projected vertically upwards, produces the exact same vertical descent, in each and every second of the entire time of flight, as it had produced in equal time when the same body was suffered to fall freely from a state of rest.

Therefore, in the fall by gravity, as modified by the resistance of the atmosphere, we have at once the inverted reading of the ascent of any ball fired vertically upwards, and we must compound the two simultaneous motions, the ascent and the descent, to obtain the actual motion of the shot.

Most unfortunately, observes Anstruther, we possess no reliable record of a time of flight exceeding 30 seconds; this may justify our inferring the fall in 40 seconds, but no more. The fall in 40 seconds is ($40^2 \times 12{\cdot}3 =$) 19,680 ft., the velocity acquired by such fall is 824 ft. a second; we are to determine the path of a ball fired vertically upwards with initial velocity 824 ft. a second, which we show in the following tabulated form;—

Seconds of Time.	Simultaneous		Actual Height A − D.	Simultaneous		Seconds of Time.
	Ascent A.	Descent D.		Descent D.	Ascent A.	
20	13960	5720	8240	5720	13960	20
19	13417·8	5198·4	8219·4	6262·2	14481·6	21
18	12855·6	4698	8157·6	6824·4	14982	22
17	12274	4219·4	8054·6	7406	15460·6	23
16	11673·6	3763·2	7910·4	8006·4	15916·8	24
15	11055	3330	7725	8625	16350	25
14	10418·8	2920·4	7498·4	9261·2	16759·6	26
13	9765·6	2535	7230·6	9914·4	17145	27
12	9096	2174·4	6922·6	10584	17505·6	28
11	8410·6	1839·2	6571·4	11269·4	17840·8	29
10	7710	1530	6180	11970	18150	30
9	6994·8	1247·4	5747·4	12685·2	18432·6	31
8	6263·6	992	5273·6	13414·4	18688·1	32
7	5523	764·4	4758·6	14157	18915·6	33
6	4767·6	565·2	4202·4	14912·4	19114·8	34
5	4000	395	3605	15680	19285	35
4	3220·8	254·4	2966·4	16459·2	19425·6	36
3	2430·6	144	2286·6	17249·4	19536	37
2	1630	64·4	1565·6	18050	19615·6	38
1	819·6	16·2	803·4	18860·4	19663·8	39
0	0	0	0	19680	19680	40

If no force were acting upon the projectile, it would, by the first law of motion, move on for ever, in a straight line, with the uniform velocity 824 ft. a second, so that if fired vertically upwards, it would, in 40 seconds, ascend to a height of (824 × 40 =) 32,960 ft. This motion is, however, in fact, modified by the action of two forces—the resistance of the atmosphere and gravity; the former of these reduces the magnitude of the ascent from 32,960 ft. to 19,680 ft. in 40 seconds' time; while the other force, gravity, in the same 40 seconds of time, is counteracting this reduced ascent, so that it brings the ball back to the spot from whence it rose, after an actual ascent of 8240 ft., which is equal to the initial velocity multiplied by one-fourth of the time of flight. Fired vertically upwards, the ball will return to the spot from whence it rose, having no range at all; but at any elevation less than 90° there will be a range which is very easily found, the ascent and the descent being both known, the difference between their squares is the square of the range.

We give Anstruther's Table, E, showing forty ranges at varying elevations for the velocity 824 ft. a second; this will enable us at once to draw the trajectory for any angle of elevation whatever. In any right-angled triangle, lay off upon the hypothenuse as many of the forty-one ascents given in our Table as the case may require, and let fall perpendiculars to show by their length the simultaneous descent—a line joining the lower ends of all these is the trajectory.

Table E.—Initial Velocity = 824 feet a second.

Time.	Ascent.	Descent.	Range.	Yards.	Log. Sin.	Elevation.		
						°	′	″
1	819·6	16·2	819·44	273·15	8·2959131	1	08	57
2	1630	64·4	1628·72	542·91	8·5966982	2	16	
3	2430·6	144	2426·33	808·77	8·7726489	3	23	49
4	3220·8	254·4	3210·74	1070·25	8·8975533	4	31	49·2
5	4000	395	3980·9	1327	8·9945871	5	40	
6	4767·6	565·2	4733·98	1570	9·0739024	6	48	
7	5523	764·4	5469·84	1823·28	9·1411557	7	57	
8	6265·6	992	6186·15	2062·05	9·1995490	9	06	34·8
9	6994·8	1247·4	6882·67	2294·22	9·2512304	10	16	
10	7710	1530	7556·67	2518·56	9·2976371	11	26	45
11	8410·6	1839·2	8206·64	2735·55	9·3398020	12	37	52·6
12	9096	2174·4	8832·28	2944·09	9·3784889	13	49	49·7
13	9765·6	2535	9430·83	3143·61	9·4142791	15	2	43·5
14	10418·8	2920·4	10001·13	3333·71	9·4476246	16	16	41·4
15	11055	3330	10541·54	3512·85	9·4788855	17	31	51
16	11673·6	3763·2	11050·4	3686·8	9·5083525	18	48	22·4
17	12274	4219·4	11525·95	3841·95	9·5363675	20	06	41·5
18	12855·6	4698	11966·42	3988·81	9·5628206	21	26	05·6
19	13417·8	5198·4	12369·88	4123·29	9·5881916	22	47	40·5
20	13960	5720	12734·33	4244·78	9·6125106	24	11	19
21	14481·6	6262·2	13057·36	4352·45	9·6359104	25	37	17·5
22	14982	6824·4	13337·46	4445·82	9·6584947	27	05	51·1
23	15460·6	7406	13570·98	4523·66	9·6803573	28	37	18
24	15916·8	8006·4	13756·52	4585·51	9·7015844	30	12	
25	16350	8625	13890	4630	9·7222413	31	50	17·6
26	16759·6	9261·2	13968·33	4656·11	9·7424166	33	32	45·8
27	17145	9914·4	13987·7	4662·59	9·7621289	35	19	44·9
28	17505·6	10584	13943·63	4644·54	9·7814728	37	12	02
29	17840·8	11269·4	13830·93	4610·31	9·8004865	39	10	23
30	18150	11970	13643·37	4547·79	9·8192176	41	15	43
31	18432·6	12685·2	13378·35	4457·78	9·8377107	43	29	14·3
31·57	18599·23	13150·21	13150·21	4383·4	9·8494377	44	59	37·55
32	18688	13414·4	13011·34	4337·11	9·8560087	45	52	
33	18915·6	14157	12515·09	4181·7	9·8741511	48	27	16·4
34	19114·8	14912·4	11958·09	3986·03	9·8918864	51	13	34·9
35	19285	15680	11227·15	3742·72	9·9101265	54	23	48·2
36	19425·6	16459·2	10317·39	3439·13	9·9280243	57	55	06·9
37	19536	17249·4	9171·33	3057·11	9·9459384	62	—	03·1
38	19615·6	18050	7679·15	2559·72	9·9638778	66	57	14·3
39	19663·8	18860·4	5562·51	1887·5	9·9818834	73	33	55·3
40	19680	19680	0·0	0·0	10·0000000	90		

The following example illustrates the nature and use of Table D;—Suppose that at elevation 4° 31′ 49·2″ (log. sin. 8·8975533) we find that the range was 3210·74 ft., then the vertical descent must be 254·4 ft., which indicates a time of flight of 4 seconds exactly. The oblique ascent of this ball we find to be 3220·8 ft., this we divide by the time, 4 seconds, the quotient, 805·2 ft. a second, is the mean velocity of the ascent. A reference to our Table shows that a velocity of 805·6 ft. is generated by gravity in 38 seconds of time; this we accept as sufficiently near. Evidently, the mean velocity of the oblique ascent will be almost the exact measure of the velocity with which the ball will be moving at the expiration of half the time of flight, that is to say, two seconds of time after quitting the muzzle, therefore (38 + 2 =) 40 seconds is the time in which gravity would generate the velocity which at elevation 4° 31′ 49·2″ ranged 3210·74 ft.

Our Table gives the graduation of this oblique ascent in the forty lines preceding 4 seconds, but this minuteness is not required; the following Table shows the trajectory for 4 seconds, calculated to half seconds of time—velocity 824 ft. a second.

Time.	Ascent.		Horizontal (Abscisses).	Vertical Descent.	Ordinates.
	Oblique.	Vertical.			
0·5	410·9125	32·456576	409·62868	4·0625	28·394076
1	819·6	64·787407	817·03931	16·2	48·537407
1·5	1225·7875	96·836569	1222·15713	36·3375	60·499069
2	1630	128·748148	1624·90737	64·4	64·346148
2·5	2031·5625	160·466210	2025·21526	100·3125	60·153710
3	2430·6	191·984831	2423·00604	144	47·984831
8·5	2827·0375	223·298087	2818·20494	195·3875	27·910587
4	3220·8	254·4	3210·7372	254·4	0·0

Table E shows that at elevation 15°, the range for initial velocity, 824 ft. a second, is 3143·6 yds., which is not very far short of the ranges obtained by the 32-pounder guns at the well-known practice at Deal in 1839. We deduce the following, among other, conclusions from our Table;—First, the angle of ascent and the angle of descent are almost exactly the same when a spherical ball is fired with the usual initial velocity at service elevation. Secondly, the height to which any ball, fired vertically upwards with velocity V, would ascend in any time T, is equal to ½ T × V exactly. Third, the course of every round projectile is nearly level from the end of the first quarter of the time of flight to the end of the third quarter of it; and, lastly, that we can in all cases of real practice determine every point of any real importance from the facts patent to all.

To show this by an example, we must employ a French record of experiments; all English records give us the angle of inclination, to use Lefroy's phrase; what we want is the angle of departure, and the French give it. At Gavre, in 1830, some very carefully-conducted experiments were recorded; we take the largest gun, the "canon de 30 long"; the following are the results, in feet, with our own calculation of the time and the velocity; the charge is 4^{k}·9 or 0·324 of the weight of the shot.

Real Elevation.			Feet Range.	Oblique Ascent.	Vertical Ascent.	Dip of the Ground.	Fall by Gravity.	Time of Flight.	Mean Velocity.
°	′	″							
0	11	13	1322·02	1322·3	4·314	13·1029	17·417	1·037	1275
1	33	22	2792·05	2793·1	75·849	17·8	93·15	2·4084	1159·7
5	4	28	5626·75	5648·8	499·644	19·886	519·53	5·75	980·66
10	27	37	8517·23	8661·2	1572·467	11·1077	1585·575	10·18	850·8

The French artillerists, reasoning on Hutton's principles, find that the initial velocity was 425 mètres, or 1394·38 ft. a second. Obviously it cannot be more than 1280 or 1290, the mean velocity in a time of only 1·037 second being 1275 ft. a second. The oblique ascent is as follows;—

Oblique Ascent.	Time.	Current Velocity.
1322·3	1·037	1275
1470·8	1·3714	1072·5
2855·7	3·3416	854·5
3012·4	4·43	850·8
8661·2	10·18	

Gen. Anstruther gives a Table, Table F, showing the fall by gravity in five seconds of time, calculated to the hundredth parts of seconds of time; this will enable us to find the time of flight for all ordinary musketry or field artillery. The range multiplied by the tangent of the elevation is the vertical ascent and descent; its length indicates the time.

TABLE F.

Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.
0·01	0·0016	0·09	0·1320	0·17	0·4706	0·25	1·0172	0·33	1·7715
2	·0065	0·1	·1629	8	·5275	6	·1001	4	·8803
3	·0147	1	·1971	9	·5877	7	·1863	5	·9925
4	·0261	2	·2345	0·2	·6512	8	·2757	6	2·1078
5	·0407	3	·2753	1	·7179	9	·3684	7	·2264
6	·0587	4	·3192	2	·7879	0·3	·4643	8	·3482
7	·0798	5	·3664	3	·8619	1	·5635	9	·4733
8	·1042	6	·4169	4	·9375	2	·6658	0·4	·6016

Table F—*continued.*

Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.
0·41	2·7331	1·11	19·9465	1·81	52·8075	2·51	101·1103	3·21	164·6492
2	·8679	2	20·3062	2	53·3893	2	1·9112	2	5·6663
3	3·0059	3	·6692	3	·9742	3	2·7152	3	6·6864
4	·1472	4	21·0353	4	54·5623	4	3·5224	4	7·7097
5	·2916	5	·4047	5	55·1536	5	4·3326	5	8·7359
6	·4393	6	·7772	6	·7480	6	5·1460	6	9·7653
7	·5903	7	22·1529	7	56·3455	7	5·9624	7	170·7977
8	·7445	8	·5318	8	·9463	8	6·7820	8	1·8332
9	·9019	9	·9139	9	57·5501	9	7·6046	9	2·8717
0·5	4·0625	1·2	23·2992	1·9	58·1571	2·6	8·4304	3·3	3·9133
1	·2264	1	·6877	1	·7672	1	9·2593	1	4·9580
2	·3935	2	24·0793	2	59·3805	2	110·0912	2	6·0057
3	·5638	3	·4742	3	·9970	3	0·9263	3	7·0565
4	·7373	4	·8722	4	60·6165	4	1·7645	4	8·1103
5	·9141	5	25·2734	5	61·2393	5	2·6058	5	9·1672
6	5·0941	6	·6778	6	·8651	6	3·4502	6	180·2272
7	·2774	7	26·0854	7	62·4941	7	4·2977	7	1·2902
8	·4638	8	·4962	8	63·1263	8	5·1482	8	2·3563
9	·6535	9	·9101	9	·7616	9	6·0019	9	3·4254
0·6	·8464	1·3	27·3273	2·	64·4	2·7	6·8587	3·4	4·4976
1	6·0425	1	·7476	1	65·0416	1	7·7186	1	5·5728
2	·2419	2	28·1711	2	·6863	2	8·5818	2	6·6512
3	·4445	3	·5978	3	66·3341	3	9·4476	3	7·7325
4	·6503	4	29·0277	4	·9851	4	120·3168	4	8·8169
5	·8593	5	·4607	5	67·6392	5	1·1891	5	9·9044
6	7·0715	6	·8969	6	68·2965	6	2·0644	6	190·9949
7	·2870	7	30·3363	7	·9569	7	2·9429	7	2·0885
8	·5057	8	·7789	8	69·6204	8	3·8244	8	3·1851
9	·7276	9	31·2247	9	70·2871	9	4·7091	9	4·2848
0·7	·9527	1·4	·6736	2·1	·9569	2·8	5·5968	3·5	5·3875
1	8·1810	1	32·1257	1	71·6298	1	6·4876	1	6·4933
2	·4126	2	·5810	2	72·3059	2	7·3815	2	7·6021
3	·6474	3	33·0394	3	·9851	3	8·2786	3	8·7140
4	·8854	4	·5011	4	73·6674	4	9·1786	4	9·8289
5	9·1866	5	·9659	5	74·2529	5	130·0818	5	200·9469
6	·3710	6	34·4339	6	75·0415	6	0·9881	6	2·0679
7	·6186	7	·9050	7	·7332	7	1·8975	7	3·1919
8	·8695	8	35·3793	8	76·4281	8	2·8099	8	4·3190
9	10·1235	9	·8568	9	77·1261	9	3·7251	9	5·4492
0·8	·3808	1·5	36·3375	2·2	·8272	2·9	4·6441	3·6	6·5824
1	·6413	1	·8213	1	78·5314	1	5·5658	1	7·7186
2	·9050	2	37·3083	2	79·2388	2	6·4906	2	8·8579
3	11·1719	3	·7985	3	·9493	3	7·4185	3	210·0003
4	·4420	4	38·2919	4	80·6629	4	8·3495	4	1·1456
5	·7153	5	·7884	5	81·3797	5	9·2825	5	2·2940
6	·9919	6	39·2880	6	82·0996	6	140·2206	6	3·4455
7	12·2716	7	·7909	7	·8226	7	1·1609	7	4·6000
8	·5546	8	40·2969	8	83·5487	8	2·1042	8	5·7575
9	·8407	9	·8061	9	81·2779	9	3·0505	9	6·9181
0·9	13·1301	1·6	41·3184	2·3	85·0103	3·	4·	3·7	8·0817
1	·4227	1	·8339	1	·7458	1	4·9525	1	9·2483
2	·7185	2	42·3526	2	86·4844	2	5·9082	2	220·4180
3	14·0174	3	·8744	3	87·2261	3	6·8669	3	1·5908
4	·3196	4	43·3994	4	·9710	4	7·8286	4	2·7665
5	·6250	5	·9275	5	88·7190	5	8·7935	5	3·9453
6	·9336	6	44·4588	6	89·4701	6	9·7614	6	5·1271
7	15·2454	7	·9933	7	90·2243	7	150·7234	7	6·3120
8	·5604	8	45·5310	8	·9816	8	1·7065	8	7·4999
9	·8786	9	46·0717	9	91·7420	9	2·6837	9	8·6908
1·	16·2	1·7	·6157	2·4	92·5056	3·1	3·6639	3·8	9·8848
1	·5246	1	47·1628	1	93·2723	1	4·6472	1	231·0818
2	·8524	2	·7131	2	94·0421	2	5·6336	2	2·2818
3	17·1834	3	48·2665	3	·8150	3	6·6230	3	3·4849
4	·5176	4	·8231	4	95·5910	4	7·6156	4	4·6910
5	·8550	5	49·3828	5	96·3701	5	8·6112	5	5·9001
6	18·1956	6	·9457	6	97·1524	6	9·6098	6	7·1122
7	·5394	7	50·5117	7	·9377	7	160·6116	7	8·3274
8	·8863	8	51·0809	8	98·7262	8	1·6161	8	9·5456
9	19·2365	9	·6533	9	99·5178	9	2·6243	9	240·7668
1·1	·5899	1·8	52·2288	2·5	100·3125	3·2	3·6352	3·9	1·9911

TABLE F—*continued.*

Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.	Time.	Fall.
3·91	243·2184	4·13	270·9830	4·35	300·2055	4·57	330·8795	4·79	362·9986
2	4·4487	4	2·2797	6	1·5683	8	2·3081	4·8	4·4928
3	5·6820	5	3·5794	7	2·9341	9	3·7398	1	5·9900
4	6·9184	6	4·8822	8	4·3030	4·6	5·1744	2	7·4901
5	8·1578	7	6·1879	9	5·6748	1	6·6120	3	8·9932
6	9·4002	8	7·4967	4·4	7·0496	2	8·0526	4	370·4993
7	250·6456	9	8·8084	1	8·4274	3	9·4962	5	2·0083
8	1·8940	4·2	280·1232	2	9·8082	4	340·9427	6	3·5204
9	3·1455	1	1·4410	3	311·1920	5	2·3923	7	5·0353
4·	4·4	2	2·7618	4	2·5788	6	3·8448	8	6·5533
1	5·6575	3	4·0856	5	3·9686	7	5·3003	9	8·0742
2	6·9180	4	5·4124	6	5·3614	8	6·7588	4·9	9·5981
3	8·1816	5	6·7422	7	6·7572	9	8·2203	1	381·1250
4	9·4482	6	8·0750	8	8·1560	4·7	9·6847	2	2·6548
5	260·7177	7	9·4108	9	9·5577	1	351·1521	3	4·1876
6	1·9903	8	290·7496	4·5	320·9625	2	2·6225	4	5·7233
7	3·2660	9	2·0915	1	2·3702	3	4·0959	5	7·2620
8	4·5446	4·3	3·4363	2	3·7810	4	5·5722	6	8·8037
9	5·8262	1	4·7841	3	5·1947	5	7·0516	7	390·3483
4·1	7·1109	2	6·1350	4	6·6114	6	8·5339	8	1·8959
1	8·3986	3	7·4888	5	8·0311	7	360·0191	9	3·4465
2	9·6893	4	8·8456	6	9·4538	8	1·5074	5·	5·

The quotation, p. 1732, showed one theory of Hutton's, which, with slight additions, is true; we shall now show another, which is totally wrong in every possible way.

Extract from Straith's Memoir of Artillery, pp. 81, 82.—"Dr. Gregory, in his lectures upon gunnery, observes on the difference between the times employed by a ball in ascending and descending vertically through the same space.

"If a 24-lb. iron ball were projected vertically upwards, with a velocity of 2000 ft. a second, it would ascend to the height of 6424 ft. before its upward motion was extinguished, and it would pass over that space in less than 9½ seconds. (This is computed in Hutton's Mathematics, vol. iii.)

"It might, on a cursory view of the subject, be supposed that the circumstances of the descent would be analogous to those of the ascent, but in an inverted order; and so they would, in a non-resisting medium, but in the air the case is widely different.

"After the ball had descended 2700 ft., the resistance of the air would be equal to the weight of the ball, there would remain no further cause of acceleration, and the ball would descend uniformly with its *terminal* velocity (that is, the greatest velocity which a heavy body can acquire when falling in the air), which does not exceed 419 ft. a second.

"It would require, therefore, $\frac{6425 - 2700}{419}$ or 6 seconds, to descend the remaining 3724 ft., in addition to the time, about 10 seconds, which had been occupied in descending through the first 2700 ft.; so that, in this instance, the time of descent would be about double that of ascent. In all cases where the projectile velocity exceeds 300 or 400 ft., the time of descent will exceed that of ascent; and their difference is greater the more the initial velocity exceeds that limit."

Here we find, observes the General, an Addiscombe professor quoting from two Woolwich professors. We are therefore sure that, at one period of his life, each artillery officer in the service believed that the descent and ascent of a ball fired upwards were successive motions, not simultaneous.

But such belief could not last long; the first time the young officer attempted to draw the trajectory of any ball from given range and elevation, we know that he did assume the abscisses; he then multiplied each abscissa by the tangent of the elevation for the vertical ascent, from which he subtracted the vertical descent, or fall by gravity, and assigned the difference between the vertical ascent and vertical descent as the ordinates of the curve. He could not have drawn a trajectory at all on any other supposition.

In the Treatise on Artillery, by Colonel Boxer, we find, pp. 144, 145, sixteen descents subtracted from sixteen ascents, the sixteen differences being given in p. 146 as the ordinates of the curve. The trajectory which he gives would leave nothing to be desired, if he would adapt his mode of calculating the flight of a projectile to some actual fact, some range and elevation recorded as having actually been observed. Perhaps the following may serve as an example:—

At Shoeburyness, on the 24th of November, 1854, the 10-in. iron howitzer of 125 cwt. gave a range of 4440 yds., or 13,320 ft. at 42° elevation. Here we say 13,320 × secant 42° = 17923·827564 ft. the oblique ascent, 13,320 × tangent 42° = 11993·38128 ft. the vertical ascent, to which latter we add 15 ft., the height of the piece above the plane, and we have 12008·38128 ft. for the vertical descent, or fall by gravity. From this we determine the time of flight; we find it to be 30·0541 seconds for $30·0541^2 \times 13·29459 = 12008·32415$ ft.

We divide the oblique ascent, 17923·827564 ft. by the time of flight, 30·0541 seconds, the quotient is 596·38, the mean velocity of the oblique ascent. We look at our printed Table and find that a ball, falling freely from a state of rest, would acquire a velocity of 596,712 ft. in 23·3 seconds of time, therefore (23·3 + 15 =) 38·3 seconds is the approximation to the greater extreme of the series, or progression, which must form the graduation of the oblique ascent. But 38·3 seconds is not sufficient; we try 39 seconds, 39·5 seconds, and 39·55 seconds, which is sufficiently accurate.

For the fall in 39·55 seconds of time is

$$\begin{array}{lrcrcl} & 39{\cdot}55^2 & \times & 12{\cdot}345 & = & 19310{\cdot}0798625 \text{ ft.} \\ \text{and in } 9{\cdot}496 \text{ seconds} & 9{\cdot}496^2 & \times & 15{\cdot}3504 & = & 1384{\cdot}2072152 \\ \hline \text{the differences} & 30{\cdot}054 & \multicolumn{3}{l}{\text{seconds of time and}} & 17925{\cdot}8726473 \text{ ft.,} \end{array}$$

show an excess of only 2·045 ft. over the oblique ascent. The velocity which the ball acquires by falling in 39·55 seconds, we find thus ;—

$$\begin{array}{lrcrcl} & 39{\cdot}55^2 & \times & 12{\cdot}345 & = & 19310{\cdot}0798625 \text{ ft.} \\ \text{and in } 39{\cdot}54 \text{ seconds} & 39{\cdot}54^2 & \times & 12{\cdot}346 & = & 19301{\cdot}8796136 \\ \hline \text{the differences} & 0{\cdot}01 & \multicolumn{3}{l}{\text{second of time and}} & 8{\cdot}2002482 \text{ ft.,} \end{array}$$

show a velocity of 820 ft. per second.

The observed time of flight was 30 seconds; this is so nearly that which we assign, that we do not hesitate to say that it proves the truth of our theory, and utterly confutes that of Hutton.

We will now conclude this by showing the true initial velocity of an actual ascent of 6424 ft. at elevation 90°; it is very easily found by inverting the reasoning, p. 1732; we there found that an actual ascent of 8240 ft. resulted from velocity 824 ft. a second, and 40 seconds' time of flight, $\frac{\text{V T}}{4} = 8240$ ft., we now say $\frac{\text{V T}}{4} = 6424$ ft.; therefore V T = 25686 ft.

We try 33·8 seconds, 33·8 × 759·147 = 25659·1686, too little;
" 33·9 " 33·9 × 760·376 = 25776·7464, too much;
" 33·83 " 32·83 × 759·45581 = 25692·3900523 ft.,

with which we are satisfied. It cannot be necessary to repeat for 33·83 seconds the process shown in p. 1732 for 40 seconds, the initial velocity which Hutton gives as 2000 ft. a second should be 759·456 ft. a second.

General Anstruther invites the mathematicians of Cambridge, or of any other place, to confirm or negative the theory which assigns to a vertical flight of 10 seconds' duration an initial velocity of only 161 ft. a second, with an actual ascent of only 402·5 ft. *Vide* Cape's Mathematics, vol. ii., p. 216.

We say that the velocity of 10 seconds' time of flight is 296 ft. a second; one-fourth of this is 74 ft., then 74 × 10 = 740 ft. the actual ascent. We give the following Table showing the motion of a ball fired vertically upwards with initial velocity 296 ft. a second.

Time, Seconds.	Simultaneous		Actual Height.	Simultaneous		Time, Seconds.
	Ascent.	Descent.		Descent.	Ascent.	
5	1135	395	740	395	1135	5
4	964·8	254·4	710·4	565·2	1275·6	6
3	765·6	144	621·6	764·4	1386	7
2	538	64·4	473·6	992	1465·6	8
1	282·6	16·2	266·4	1247·4	1513·8	9
0	0	0	0	1530	1530	10

We say that at 45° elevation the range for 10 seconds' time of flight is 1530 ft., and that we can determine the initial velocity which would give that range by a very simple process; thus, we draw a square, each side representing 1530 ft., and we draw a diagonal measuring $1530\sqrt{2}$ ft., or 2163·75 ft. This diagonal will represent the oblique ascent in the time of flight, 10 seconds; we see at a glance that the mean velocity of the oblique ascent, 2163·75 ft. in 10 seconds, is 216·375 ft. a second, and our printed Table shows us that a fall of 7·1 seconds' duration would give a velocity of 216·336, almost exactly the mean velocity of the oblique ascent.

The time when the ball is moving with the mean velocity is sure to be very nearly the middle period of the time of flight, so that 5 seconds after, and 5 seconds before, 7·1 seconds, that is 12·1 and 2·1 seconds, will be the 10 seconds in our Table which give the graduations of the oblique ascent. More correctly it would be 12·2 seconds and 2·2 seconds, still more correctly 12·19 and 2·19 seconds. For the fall in 12·19 seconds of time is

$$\begin{array}{lrcl} & 12{\cdot}19^2 \times 15{\cdot}081 & = & 2240{\cdot}9777841 \text{ ft.} \\ \text{and in } 2{\cdot}19 \text{ seconds} & 2{\cdot}19^2 \times 16{\cdot}081 & = & 77{\cdot}1260841 \\ \hline & & & 2163{\cdot}8517 \text{ ft., only } 0{\cdot}1 \text{ ft. too much.} \end{array}$$

The following are the abscisses and ordinates;—

Time.	Abscisses.	Differences.			Ordinates.
		1.	2.	3.	
1	240·467338	240·467338			240·267338
2	462·630509	222·203171	18·304167	0·424264	398·231009
3	666·065249	203·434740	18·728431		522·065249
4	850·347294	184·282045	19·152695		595·947294
5	1015·052380	164·705086	19·576959		620·052380
6	1159·756243	144·703863	20·001223		594·556243
7	1284·034619	124·278376	20·425487		519·634619
8	1387·463244	103·428625	20·849751		395·463244
9	1469·617850	82·154610	21·274015		222·217850
10	1530·074181	60·456331	21·698279		0·074181

We have given these abscisses and ordinates because that is the usual method of defining a curve; it is, however, a very bad method, not one figure being of any use at any other elevation. We give now the simultaneous ascent and descent for all elevations whatever.

Time.	Ascent.	Differences.			Descent.
		1.	2.	3.	
1	340·07217	340·07217			16·2
2	654·25834	314·18617	25·886	0·6	64·4
3	941·95851	287·70017	26·486		144
4	1202·57268	260·61417	27·086		254·4
5	1435·50085	232·92817	27·686		395
6	1640·14302	204·64217	28·286		565·2
7	1815·89919	175·75617	28·886		764·4
8	1962·16936	146·27017	29·486		992
9	2078·35353	116·18417	29·086		1247·6
10	2163·85170	85·49817	30·686		1530
11	2218·06387	54·21217	31·286		1839·2
12	2240·39004	22·32617	31·886		2174·4
12·19	2240·9777841				2240·9777841

The velocity acquired by falling in 12·19 seconds, we find thus;—

The fall in	12·2 seconds is	2244·5072 ft.
and in	12·19 „	2240·9777841
the differences being	0·01 second and	3·5124159 ft.,

show a velocity of 351·94, say 352 ft. a second.

That the range at 45° elevation is the exact measure of the fall by gravity in the time of flight is an acknowledged fact, yet we find the British gunner assigning different ranges to the same elevation and time of flight, 45° and 10 seconds.

We read that the range of the 10-in. land mortar was 534 yds. in 10 seconds, at 45° elevation; that of the 8-in., 560 yds.; so that the fall by gravity in 10 seconds was 1602 ft., or $t^2 \times 16{\cdot}02$, as shown by the 10-in., or else 1680 ft., or $t^2 \times 16{\cdot}8$, as shown by the 8-in. We say it is 1530 ft., or $t^2 \times 15{\cdot}3$, as registered in the General's Table.

The President of the special committee on breech-loading rifles informed Anstruther that they do not consider the angles given in p. 23 of their report to be sufficiently accurate to furnish data for calculation, and that the initial velocity was really very much greater than he gave it.

It is to be regretted that the committee did not measure the true angle of departure in the manner adopted by the French at Gavre, in the years 1830 to 1840, who placed a screen 30 ft. in front of the muzzle, and measured the actual angle at which the shot did leave the gun.

The following were the oblique ascents and vertical descents of the largest gun, the "canon de 30 long," with the smallest charge, $2^{k}{\cdot}45$.

Range 323 mètres, or 1059·73 ft., had

Oblique ascent	1059·8 ft.
Vertical descent	14·396 ft.
Therefore, a time of flight..	0·94 second
And a mean velocity of ascent $\left(\frac{1059{\cdot}8}{0{\cdot}94} =\right)$ ..	1127·44 ft. a second.

Hence we know that at the expiration of 0·47 second, the velocity of this ball was 1127·44 ft. a second.

Again, the range being 712 mètres, or 2336 ft.,

The oblique ascent was .. .. 2337 ft.
The vertical descent .. .. 83·09 ft.
The time of flight .. .. 2·27 seconds
And a mean velocity of $\left(\frac{2337}{2·27} =\right)$ .. .. .. 1029·5 ft. a second,

which is the velocity with which it was moving at 1·135 second after quitting the muzzle.

Comparing these two, at 0·47 second, the velocity was 1127·44 ft.
1·135 „ „ „ 1029·5
the differences are 0·665 „ and 97·94 ft.,

showing a rate of reduction of about 147 ft. in a second.

Supposing that the ball lost half of this velocity in the 0·47 second of its first flight, we add 74 ft. a second to the 1127·44 ft. of the first range, and give (1127·44 + 74 =) 1201 ft., say 1200 as the initial velocity of the ball. The French artillerists give it as 363 mètres, or 1190·966 ft., almost exactly what Anstruther's simple and easy calculation makes it.

Example, to show how Table E is applied.—On the supposition that the largest projectile will be most easily observed, and that the longest gun will give the most accurate results, we have selected our data from page 390 of the Ordnance Manual of the American Artillery. The bore of the piece is 15 in. in diameter, 165 in. in length.

The 15-in. columbiad, with 40 lbs. of powder, gave the following ranges, namely, at

9° elevation, 2236 yds., or 6708 ft. in 8·87 seconds' time.
10° „ 2425 „ 7275 „ 10 „
12° „ 2831 „ 8493 „ 12·07 „
15° „ 3078 „ 9234 „ 13·72 „
20° „ 3838 „ 11514 „ 17·82 „
25° „ 4528 „ 13584 „ 22·03 „
28° „ 4821 „ 14463 „ 24·18 „
30° „ 5018 „ 15054 „ 26·71 „

The angles here named are evidently the "angles of inclination," as shown by a spirit-level quadrant, and not the "angles of departure," those which the path of the shot makes with the horizon, as it clears the mouth of the piece; but the recorded time of flight enables us to find the vertical ascent, from which we can determine the angle of departure.

The vertical descent is the fall by gravity: our Table shows us that the fall in

8·87 seconds is $8·87^2 \times 15·413 = 1212·6470597$ ft.
10 „ $10^2 \times 15·3 = 1530$
12·07 „ $12·07^2 \times 15·093 = 2198·8221857$
13·72 „ $13·72^2 \times 14·928 = 2810·0228352$
17·82 „ $17·82^2 \times 14·518 = 4610·2257432$
22·03 „ $22·03^2 \times 14·297 = 6841·5687273$
24·18 „ $24·18^2 \times 13·882 = 8116·4222568$
26·71 „ $26·71^2 \times 13·629 = 9723·2570589$

There must have been a vertical ascent to enable the ball to have this vertical descent, we deduce the following eight triangles;—

Triangle.	Horizontal.	Vertical.	Oblique.	Triangle.	Horizontal.	Vertical.	Oblique.
I.	6708	1212·647	6818·7	V.	11514	4610·226	12402·6
II.	7275	1530	7434·15	VI.	13584	6841·569	15209·6
III.	8493	2198·822	8773	VII.	14463	8116·422	16584·7
IV.	9234	2810·023	9652·1	VIII.	15054	9723·257	17921·067

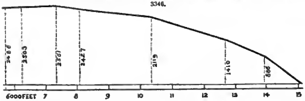
The last of these triangles we must examine carefully.

Knowing the three sides, we find the acute angles to be

32° 51′ 29·1″, log. sin. 9·7344479
and 57° 8′ 30·9″, „ 9·9242881;

we draw a triangle with these angles, and upon the hypothenuse we mark off all the eight oblique ascents given p. 1732, then from the points so found let fall successively the eight vertical

3346.



descents, join the lower ends of all the verticals; the curve so found is the trajectory required, as in Fig. 3346.

The calculated measurements of this curve are as follows;—

Abscisses.	Simultaneous		Ordinates.	Abscisses.	Simultaneous		Ordinates.
	Ascent.	Descent.			Ascent.	Descent.	
5726·145	3698·467	1212·647	2485·82	10416	6729·151	4610·226	2118·925
6224·812	4033·47	1530	2503·47	12777·322	8252·117	6841·569	1410·548
7369·47	4759·876	2198·842	2561·054	13934·637	9002·261	8116·422	885·839
8107·927	5236·841	2810·023	2426·818	15054	9723·257	9723·257	0·0

We must now determine the initial velocity of this ball, which we easily do, from the fact that it did ascend obliquely to a distance of 17921·067 ft. in 26·71 seconds, with a simultaneous vertical descent of 9723·257 ft. If this ball had been fired vertically upwards, then at 8197·81 ft. above the plane would have been its place at the expiration of 26·71 seconds of time.

We know that if a ball be projected upwards vertically, with the velocity which it acquired in any time by descending freely, it would, *if not acted upon by gravity*, lose all velocity in an equal time, and would, *if not acted upon by gravity*, ascend just to the same height from which it fell, and, in so doing, would describe equal spaces in equal times, in rising and falling, but in an inverse order; and it would have equal velocities at any one and the same point of the line described both in ascending and descending.

Our last paragraph, except the words in italics, is taken from Hutton, as quoted by Gregory and Rutherford. The words in italics added by the General are necessary.

We have therefore only to turn to our Table showing the fall of gravity as modified by the resistance of the atmosphere, to find the 267 lines which will give the graduation of the oblique ascent of this ball, and we have a very simple method of finding the place by finding the mean velocity; the space 17,921 ft. divided by the time 26·7 seconds, gives 671·2 ft. a second as the mean velocity of the ascent, which we see must be nearly the velocity with which the ball will be moving at the middle period of the time of flight, that is to say, at 13·35 seconds from clearing the mouth of the piece. Now velocity 671·2 is acquired by a fall of 27·6 seconds, we add 27·6 and 13·35, the sum 40·95 seconds is an approximation to the true time.

But 42·1 seconds is nearer the truth, as we shall show.

The fall in 42·1 seconds is $42·1^2 \times 12·09 = 21428·4369$ ft.
and in 15·4 „ $15·4^2 \times 14·76 = 3500·4816$

the differences being 26·7 seconds of time and 17927·9553 are only 7 ft. too much.

We shall, however, be satisfied with 42 seconds as near enough.

The fall in 42 seconds is $42^2 \times 12·1 = 21344·4$
and in 15·3 „ $15·3^2 \times 14·77 = 3457·5093$

17886·8907 ft.,
which is too short by 34

as it ought to be 17921·

Our Table shows that the velocity acquired by a fall of 42 seconds is 840 ft. a second; this is therefore the initial velocity, which at the elevation (true) 32° 51′ 29·1″ gave a range of 5018 yds.

Now let us suppose that the ball is fired vertically upwards with initial velocity 840 ft. a second, it is very evident that, if no force were acting upon the projectile, it would, by the first law of motion, move on for ever in the line of direction given to it, and would ascend to a height of ($42 \times 840 =$) T V = 35280 ft. in 42 seconds; the resistance of the atmosphere reduces this to 21344·4 ft.; and the force of gravity causes a simultaneous descent of 21344·4 ft., so that the ball returns to the ground, having in exactly half the time of flight attained a vertical height of exactly one-fourth part of T V, that is to say, 8820 ft., the fourth part of 35,280 ft.

Why the actual ascent, at 90° elevation, should always be exactly the fourth part of T V, we need not inquire; such is the fact. We shall show another example of it. A ball fired vertically with initial velocity 636·224 ft. per second, will return to the ground in 25·5 seconds, having ascended in 12·75 seconds to a height equal to 25·5, multiplied by one-fourth part of 636·224, which is 159·056 ft., so that ($25·5 \times 159·056 =$) 4055·928 ft. is the real height attained. This is a correction of the height assigned to this ball in p. 381 of vol. ix. of the Journal of the Royal United Service Institution, where the height is given as 4055·93275 ft., which is 0·00675 ft. too much; the velocity there assigned to this time of flight is 636·1385 ft., it should be 636·224. The cause of the error is to be found in page 375, where the velocity acquired by a fall of 25·5 seconds is found by taking the difference between 25·5 and 25·49 seconds; it should have been done by taking the difference between 25·5 and 25·4999999999999 seconds. The true ascent is one-fourth of T V in all possible cases, but this was not known in A.D. 1865.

Hutton supposed that an initial velocity of 2000 ft., at 90° elevation, would culminate in "less than 9½ seconds" at a height of 6424 ft., returning to the ground in "about" 16 seconds. He did not perceive that the ascent and the descent were simultaneous, and in this error he was followed by Gregory and Straith, and most probably by many others.

It is gratifying to be able to show that General Boxer, R.A., in his treatise on Artillery, gives the following;—

Abscisses.	Simultaneous		Ordinates.	Abscisses.	Simultaneous		Ordinates.
	Ascent.	Descent.			Ascent.	Descent.	
100	0·87269	0·05624	0·81645	900	7·85421	5·1328	2·72141
200	1·74538	0·2285	1·51688	1000	8·7269	6·4193	2·3076
300	2·61807	0·52211	2·09596	1100	9·59959	7·874	1·72559
400	3·49076	0·94233	2·54843	1200	10·57228	9·4982	0·97408
500	4·36345	1·4945	2·86895	1300	11·34497	11·296	0·04897
600	5·23614	2·1837	3·05244	1100	12·21766	13·274	— 1·05634
700	6·10883	3·0157	3·69313	1500	13·09035	15·436	— 2·34565
800	6·98152	3·9954	2·98612	1600	13·96304	17·79	— 3·82696

The following tabulated form shows the measurements of the curve described by the ball which, at elevation 32° 51′ 29·1″, obtained a range of 5018 yds.;—

Abscisses.	Simultaneous		Ordinates.	Abscisses.	Simultaneous		Ordinates.
	Ascent.	Descent.			Ascent.	Descent.	
702·42	453·7	16·2	437·5	9601·4	6201·5	3330	2871·5
1298·12	903	64·4	838·6	10150·1	6555·9	3763·2	2792·7
2086·6	1347·7	144	1203·7	10684·5	6901·1	4219·4	2681·7
2767·35	1787·4	254·4	1533	11204·2	7236·7	4698	2538·7
3439·87	2221·8	395	1826·8	11708·5	7562·4	5198·4	2364
4103·65	2650·5	565·2	2085·3	12197·1	7877·9	5720	2157·9
4758·19	3073·3	764·4	2308·9	12669·3	8182·9	6262·2	1920·7
5403	3489·7	992	2497·7	13124·8	8477·1	6824·4	1652·6
6037·54	3899·6	1247·4	2652·2	13563	8760·2	7406	1354·2
6661·34	4302·5	1530	2772·5	13983·3	9031·6	8006·4	1025·2
7273·88	4698·1	1839·2	2858·9	14385·4	9291·3	8625	666·3
7874·66	5086·2	2174·4	2911·8	14768·6	9538·6	9261·2	277·4
8463·18	5466·3	2535	2931·3	15131·5	9773·6	9914·4	— 140·8
9038·93	5838·2	2920·4	2917·8				

If this ball were now fired vertically upwards, its time of flight would be 42 seconds, its motions as follows, namely;—

Seconds of Time.	Simultaneous		Actual Height attained.	Simultaneous		Seconds of Time.
	Ascent.	Descent.		Descent.	Ascent.	
21	15082·2	6262·2	8820	6262·2	15082·2	21
20	14520	5720	8800	6824·4	15624·4	22
19	13938·4	5198·4	8740	7406	16146	23
18	13338	4698	8610	8006·4	16646·4	24
17	12719·4	4219·4	8500	8625	17125	25
16	12083·2	3763·2	8320	9261·2	17581·2	26
15	11430	3330	8100	9914·4	18014·4	27
14	10760·4	2920·4	7840	10584	18424	28
13	10075	2535	7540	11269·4	18809·4	29
12	9374·4	2174·4	7200	11970	19170	30
11	8659·2	1839·2	6820	12685·2	19505·2	31
10	7930	1530	6400	13414·4	19814·4	32
9	7187·4	1247·4	5940	14157	20097	33
8	6432	992	5440	14912·4	20352·4	34
7	5664·4	764·4	4900	15680	20580	35
6	4885·2	565·2	4320	16459·2	20779·2	36
5	4095	395	3700	17249·4	20949·4	37
4	3294·4	254·4	3040	18050	21090	38
3	2484	144	2310	18860·4	21200·4	39
2	1664·4	64·4	1600	19680	21280	40
1	836·2	16·2	820	20508·2	21328·2	41
			0	21344·4	21344·4	42

It is much to be regretted that we have not any record of practice at great elevations, which would give us the measure of the fall by gravity in 50, 60, or even 70 seconds of time. As there is no limit to the resistive strength that might be given to the 15-in. columbiad, by shrinking on steel tubes, there can be no reason why this piece, which, with a charge of 40 lbs. of powder, at elevation 74° 3' 38·7", would get a range of 1950 yds., should not be fired at an elevation of 85° with a charge of 80 or 100 lbs. of powder; the observed time of flight and measured range would be very instructive. At present the 42 seconds' flight is the very outside of the limit we can calculate with certainty; our Table of the series or progression fails altogether at 54·4".

TABLE G.

Time.	Abscissæ.		Simultaneous			Ordinates.		
			Ascent.		Descent.			
		Diff.		Diff.			Diff. 1.	Diff. 2.
1	702·4223	702·4223	453·6889	453·6889	16·2	437·4889	437·4889	
2	1298·1245	695·7022	903·0373	49·3484	64·4	838·6373	401·1484	36·066
3	2086·6026	88·4781	1347·7197	44·6824	144	1203·7197	365·0824	35·7915
4	2767·3526	80·75	1787·4106	39·6909	254·4	1533·0106	329·2909	35·617
5	3439·8705	72·5179	2225·7845	34·3739	395	1826·7845	293·6739	35·1425
6	4103·6523	63·7818	2650·5159	28·7314	565·2	2085·3159	258·5314	34·968
7	4758·1940	54·5417	3073·2793	22·7634	761·4	2308·8793	223·5634	34·6935
8	5402·9916	44·7976	3489·7492	16·4699	992	2497·7492	188·8699	34·419
9	6037·5411	34·5495	3899·6001	09·8509	1247·4	2652·2001	154·4509	34·1444
10	6661·3385	23·7974	4302·5065	02·9064	1530	2772·5065	120·3065	33·8701
11	7273·8798	12·5413	4698·1429	395·6364	1839·2	2858·9429	86·4364	33·5855
12	7874·6610	00·7812	5086·1838	88·0409	2174·4	2911·7838	52·8509	33·2472
13	8463·1781	588·5171	5466·3037	80·1199	2535	2931·3037	19·5199	33·3310
14	9038·9271	75·749	5838·1771	71·8734	2920·4	2917·7771	13·5266	33·0465
15	9601·4040	62·4769	6201·4785	63·3014	3330	2871·4785	46·2986	32·7720
16	10150·1048	48·7008	6555·8824	54·4039	3763·2	2792·6824	78·0961	31·7975
17	10684·5255	34·4207	6901·0633	45·1809	4219·4	2681·6633	111·0191	32·9230
18	11204·1621	19·6366	7236·6597	35·5964	4698	2538·6597	143·0036	32·9845
19	11708·5106	04·3485	7562·3821	25·7224	5198·4	2363·9821	174·6776	31·6740
20	12197·0750	488·5644	7877·9050	15·5229	5720	2157·9050	206·0771	31·3995
21	12669·3433	72·2683	8182·9029	04·9979	6262·2	1920·7029	237·2021	30·1250
22	13124·8115	55·4682	8477·0503	294·1474	6824·4	1652·6503	268·0526	30·8505
23	13562·9756	38·1641	8760·1762	82·9714	7406	1354·1762	298·4741	30·4215
24	13983 3316	20·356	9031·6461	71·4699	8006·4	1025·2461	328·9301	30·4560
25	14385·3755	02·0439	9291·2890	59·6429	8625	666·2890	358·9571	30·0270
26	14768·6033	383·2278	9538·6249	47·4904	9261·2	277·4249	388·8641	29·9070
27	15131·5110	63·9077	9773·6373	35·0124	9914·4	−140·7627	428·1876	29·3235

TABLE II.—ELEVATIONS.—INITIAL VELOCITY 840 FEET A SECOND.

Time.	Ascent.		Descent.	Logm. Sine.	Elevation.			Ranges.	
					°	′	″	feet.	yards.
1	836·2	836·2	16·2	8·2872048	1	6	36	836	279
2	1664·4	28·2	64·4	5876282	2	13		1663·1	554
3	2484	19·6	144	7632109	3	19		2479·8	826·6
4	3294·4	10·4	254·4	8872138	4	25		3288·5	1096
5	4095	00·6	395	9843432	5	32		4075·9	1359
6	4885·2	790·2	565·2	9·0633199	6	38		4852·4	1617·5
7	5664·4	79·2	764·4	·1301668	7	45		5612·6	1871
8	6432	67·6	992	881657	8	52		6355	2118
9	7187·4	55·4	1247·4	·2394339	9	59		7078·3	2359
10	7930	42·6	1530	854182	11	7		7845	2615
11	8659·2	29·2	1839·2	·3271512	12	15		8461·6	2820·5
12	9374·4	15·2	2174·4	653959	13	24		9118·7	3039·6
13	10075	00·6	2535	·4007340	14	34		9750·8	3250
14	10760·4	685·4	2920·4	336139	15	44		10356·5	3452
15	11430	69·6	3330	643980	16	55		10938·3	3646
16	12083·2	54·2	3763·2	933753	18	8		11482·2	3827
17	12719·4	36·2	4219·4	·5207841	19	22		11999·3	3999·8
18	13338	18·6	4698	468223	20	37		12483·2	4161
19	13938·4	00·4	5198·4	716568	21	53		12932·7	4311
20	14520	581·6	5720	954294	23	11		13345·8	4449
21	15082·2	62·2	6262·2	·6182622	24	31		13720·7	4573·6
22	15624·4	42·2	6824·4	402612	25	53		14055·2	4685
23	16146	21·6	7406	615188	27	18		14343·8	4781
24	16646·4	00·4	8006·4	821270	28	44		14598·2	4866
25	17125	478·6	8625	·7021285	30	14	30·3	14794·44	4931·5
26	17581·2	56·2	9261·2	216188	31	47		14944·3	4981
27	18014·4	33·2	9914·4	406466	33	23		15040·2	5013

TABLE H—*continued.*

Time.	Ascent.		Descent.	Logm. Sine.	Elevation.			Ranges.	
					°	′	″	feet.	yards.
28	18424	409·6	10584	9·7592659	35	3		15080·5	5027
29	18809·4	385·4	11269·4	775259	36	48		15059·6	5020
30	19170	60·6	11970	954721	38	38		14973·6	4991
31	19505·2	35·2	12685·2	·8131469	40	34		14816·8	4939
32	19814·4	09·2	13414·4	305903	42	36		14583	4861
33	20097	282·6	14157	478400	44	47		14264·2	4754·7
34	20352·4	55·4	14912·4	649319	47	6		13850·2	4617
35	20580	27·6	15680	819007	49	38		12329·4	4443
36	20779·2	119·2	16450·2	987799	52	22		12687·3	4229
37	20949·4	170·2	17249·4	·9166024	55	37		11803·7	3934·6
38	21090	140·6	18050	824006	58	51		10908	3636
39	21200·4	110·4	18860·4	492068	62	49	34·02	9682	3227
40	21280	79·6	19680	660535	67	39		8095·4	2698·5
41	21328·2	48·2	20508·2	829733	74	3		5857·1	1952·4
42	21344·4	16·2	21344·4	10·0000000	90			0·0	0·0

TABLE I.—ELEVATION 45°.

Range.		Time of Flight.	Oblique Ascent.	Mean Velocity.	Initial Velocity.
yards.	feet.				
100	300	4·35	424·264	97·53	162·88
200	600	6·2	848·528	136·86	227·624
300	900	7·61	1272·792	167·25	275·88
400	1200	8·82	1697·056	192·31	315·7
500	1500	9·9	2121·32	214·27	349
600	1800	10·87	2545·584	234·07	380·5
700	2100	11·79	2969 848	251·9	407·2
800	2400	12·63	3394·112	268·73	433·2
900	2700	13·45	3818·376	283·88	454·4
1000	3000	14·2	4242·64	298·8	476·411
1100	3300	14·93	4666·904	312·58	496·112
1200	3600	15·63	5091·168	325·73	515·327
1300	3900	16·3	5515·432	338·37	533
1400	4200	16·96	5939·696	349·04	554
1500	4500	17·59	6363·96	361·19	565·1
2000	6000	20·52	8485·28	413·41	634·5
2500	7500	23·15	10606·6	458·17	690
3000	9000	25·6	12727·92	497·18	734·656
3500	10500	27·88	14849·24	532·54	772·336
4000	12000	30·05	16970·56	564·71	805·1
4500	13500	32·11	19091·88	594·46	830
5000	15000	34·12	21213·2	621·72	850

We will hereafter describe two useful instruments, adapted by Major-Gen. Anstruther, in his investigations respecting the motion of projectiles.

When the parabolic theory of the motion of projectiles in vacuo was first brought forward it was supposed by many clever men that the resistance of the fluid in which a projectile must necessarily move might be disregarded in calculation, or that at least a compensation might be found by experiment or otherwise which would render the parabolic theory capable of practical application. Persons who in those remote times were sceptical on this point would most likely have been treated with the same kind of good-natured contempt that anyone in the present day would meet with who dared to express a doubt as to the truth of the generally-received doctrine, that the application of the parabolic theory in practice is quite inadmissible on account of the resistance of the air to a projectile moving with the velocity which it is practically necessary to consider. It is the fashion to assert as an indisputable fact that nothing can be further from the true trajectory of a projectile subject to the resistance of the air, and moving with a considerable velocity, than a parabolic curve, and this we are told *everybody knows*; if everybody also knew what the true curve of the trajectory was, we should be in a very favourable position for solving all the useful practical problems appertaining to the science of gunnery; but here we are left completely in the dark, to arrive at the conclusion that what the real curve of a trajectory is, *nobody knows.*

The question therefore naturally arises, What are we to do? If theory, as it is called, unsupported by practical results, cannot be relied upon, and must consequently be altogether disregarded, isolated experiments, without the support of some theory enabling us to generalize, classify, and arrange the results of practice, so as to render them applicable to all circumstances, are little if at all better than the disregarded theory. That the range of a projectile moving through the air falls far short of the range calculated upon the supposition that this same projectile moves in vacuo, is a well-known fact; but at the same time, we approach nearer and nearer to a coincidence with the calculated range as the projective force and velocity are diminished. It could hardly have been expected that calculations established upon the supposition that the projectile moved in vacuo should be found applicable in practice without certain modifications; but it was at first supposed that a system of compensation or rectification might be easily arrived at, which would bring the disturbing elements caused by the resistance of the atmosphere and other causes quite within manageable limits, and that the established theory would not only serve as a sure guide to experiment, but also as the means of generalizing and forming practical rules. But this idea seems to have been long abandoned. The force of resistance, at first almost ignored, seems to be now exaggerated to such a degree that all thoughts of attempting to establish a practical theory seem to be hopelessly relinquished. We seem to have got into a kind of chaos of ideas on the subject of projectiles, without anything to rest upon besides a blind reliance upon tables, which we worship and believe in, and which are framed according to a system which, of course, *everybody knows*, but which nobody could exactly describe to you if they were individually asked, and upon an implicit faith in some old traditional rules with reference to what are called the laws of gravity, which have been preserved for ages, and are reproduced as a matter of course in all works upon gunnery.

The laws of gravity seem to be like the laws of the Medes and Persians, which no one, except Anstruther, should gainsay or attempt to alter; and consequently they seem to have been taken as the starting point of all discussions respecting the theory of projectiles, and no one, except Anstruther, has been so wicked as for a moment to question the truth of these time-honoured institutions, consequently they have remained unaltered, as venerable monuments of the past.

That our theory of projectiles has proved a practical failure few will be disposed to deny. But the following question remains to be answered, Shall we relinquish all further theoretical inquiry, drop the matter in despair, and trust to experiment, tables, trial shots, and chance? or shall we do what a sensible workman generally does when his first effort at success is unsatisfactory, namely, look to his tools and machinery to see that there is no flaw of construction or no miscalculation as to the principles of action, and also look about him to see if there are no modern discoveries or new scientific inventions which may assist him in arriving at the required result? In the present article we propose to take the latter course, and in the first place to say a few words about the laws of gravity, which may be considered as the machinery and tools with which we have been working so long. That the resistance of the air must form an important element in all calculations with reference to the trajectory of projectiles there can be little doubt; but we think it is at least questionable whether we ought to attribute the whole of the glaring discrepancy which is found to exist between theory and practice to that cause alone. It will be at least worth while to examine the matter in detail, in order to ascertain if there are not other sources of error, and whether corrections cannot be applied so as to bring the total amount within manageable limits.

Suppose a curve either convex or concave to the axis of the abscisses to be of such a nature that while the abscisses denote the time, the corresponding ordinates shall denote the measure of the force during such time; then, because effects are proportionate to their causes, the instantaneous velocities produced or generated by the forces are proportionate to the forces which generate them. $d a = y \, . \, d x$ expresses the differential of the area included by a curve, and the ordinates of any points upon it, as the function of the co-ordinates; therefore, substituting v for a, f for y, and t for x, we have $d v = f \, . \, d t$. Taking as before the abscisses to express the time, but the corresponding ordinates to denote the velocities generated or produced, it will be evident that in this case in the expression $d a = y \, . \, d x$, a may be taken to represent the space passed over with the velocity indicated by the abscisses; we may therefore substitute s for a, v for y, and as before, t for x, which gives $d s = v \, . \, d t$. When we have to deal with uniform velocity we may take v as constant; therefore, integrating the last expression, $s = v t$, from which we deduce the following;—

In uniform velocity—

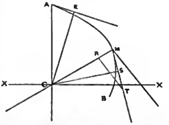
1. The spaces described in the same time are as the velocities.
2. The spaces described with the same velocity are as the times.
3. Spaces described with unequal velocities and in different times are as the velocities and times conjointly.

There can be no doubt whatever that the above expressions are correct exponents of the value of uniform forces or velocities under all the circumstances to which they may be applied. But with reference to the subject we are now dealing with, uniform force or the resulting uniform velocity can be only taken as a measure of, or as a means of indicating the comparative values of the varying forces, or of the accelerated or retarded velocities involved in the motion of bodies subjected to the influence of attraction combined with that of a projectile force, while passing through a resisting medium. We here enter upon a very intricate subject, so difficult that in order to facilitate calculation we seem to have condoned many errors in theory as being separately too minute and insignificant to have any important effect upon the practical result, the consequence of which appears to be that the aggregate has produced an amount of accumulated error which renders our calculations practically useless, and then we exonerate ourselves by laying the whole blame upon the atmosphere. We can only estimate or compare forces by noting their effects upon matter with which we are conversant, and then by a careful analysis and comparison endeavour to deduce as close an approximation as possible to the laws of action of the forces under investigation. Leaving out of consideration slight deviations and perturbations, we may assume as an established fact that the orbits of the heavenly bodies subjected to the influences of attraction and some original mysterious projectile force are elliptical. This, due to John Kepler, is at least the closest approximation to their line of motion which we have as yet arrived at.

Starting from this point, we shall now proceed to show that if the centre of force be situated in one of the foci of an ellipse, a body whose line of motion is on the periphery must be attracted by a force whose intensity is inversely proportional to the square of the distance from the centre of attraction, and that therefore this is the closest approximation to the law of attraction which we have as yet attained to. In order to this we shall in the first place establish two equations with reference to centripetal forces in general.

We shall suppose that a body projected from a given point A, Fig. 3347, in a given direction A E, with a given velocity, is attracted by a force which acts according to any law whatever towards a fixed point C. Take the curve A M B, which we will express by z, to represent the locus of motion of a particle subject to the combined influences of the projectile and attractive forces; C A, C M radii vectors, which we will represent by y, indicating the lines of action of the attractive force at any points A and M in the curve A M B; A E, M S tangents at the points A and M, and C E, C S perpendiculars upon the tangents from the fixed point C.

3347.



From any point T in the tangent at M let fall the perpendicular T R upon the line C M. Then T M, M R, T R, may be taken respectively to represent dz, dy and dx.

By the resolution of forces C M, M S as the force in the direction C M is to the force in the direction of the tangent at the point M. By similar triangles M T : M R :: C M : M S; or if we take f to express the centripetal force at the point M, $dz : dy :: f : \frac{dy}{dz} f$, which evidently expresses the force in the direction of the tangent at M. Substituting this value for f in the expression $dv = f \, . \, dt$ (f is for force in general), we obtain $dv = \frac{dy}{dz} f \, . \, dt$; $dv \, . \, dz = f \, . \, dy \, . \, dt$; $\frac{dv \, . \, dz}{f \, . \, dy} = dt$. Eliminating dt by means of the equation $ds = v \, . \, dt$, which in this case is represented by $dz = v \, . \, dt$, we get $\frac{dv \, . \, dz}{f \, . \, dy} = dt = \frac{dz}{v}$; $v \, . \, dv = f \, . \, dy$, which, when y increases as the velocity v diminishes, becomes $v \, . \, dv = - f \, . \, dy$.

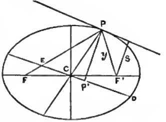
Taking the two equations already established, $dv = f \, . \, dt$ and $dz = v \, . \, dt$, upon the supposition that the evanescent intervals of time are equal to each other, and consequently dt uniformly constant, the differential of the latter expression becomes $d^2 z = dv \, . \, dt$. Substituting the above value for dv, we have $d^2 z = f \, . \, dt^2$. C M : C S as the force in the direction C M is to the force in the direction perpendicular to the tangent at M. Taking s to represent the perpendicular C S, we have $y : s :: f : \frac{s}{y} f$, which represents the force in the direction perpendicular to the tangent at M. Substituting this value for f in the above expression, we have $d^2 z = \frac{s}{y} f \, . \, dt^2$. By similar triangles T M : M R :: C M : M S, $dz : dy :: y : \frac{y \, . \, dy}{dz}$; therefore $\frac{y \, . \, dy}{dz} = $ M S. The radius M S is to the radius M T as the differential of the circular arc described by the point S (which may evidently be represented by ds, the differential of the tangent at that point) to the differential of the circular arc described by the point T, which may be taken to represent the second differential of z with respect to the space T M $= dz$. Therefore $\frac{y \, . \, dy}{dz} : dz :: ds : \frac{ds \, . \, dz^2}{y \, . \, dy}$, $\frac{ds \, . \, dz^2}{y \, . \, dy} = d^2 z$; therefore $\frac{s}{y} f dt^2 = d^2 z = \frac{ds \, . \, dz^2}{y \, . \, dy}$, $\frac{s}{y} f dt^2 = \frac{ds \, . \, dz^2}{y \, . \, dy}$; but $dz = v dt$, $\frac{dz^2}{v^2} = dt^2$. Substituting this value for dt^2, $\frac{s}{y} f \frac{dz^2}{v^2} = \frac{ds \, . \, dz^2}{y \, . \, dy}$, $f \, . \, dy \, . \, s = v^2 \, . \, ds$.

Having now established the two equations $v \, . \, dv = - f \, . \, dy$ and $f \, . \, dy \, . \, s = v^2 \, . \, ds$, we can eliminate f. $- \frac{v dv}{dy} = f = \frac{v^2 ds}{dys}$, $- s \, . \, dv = v \, . \, ds$, $v \, . \, ds + s dv = 0$. Integrating, we get $v \, . \, s = C$. Taking d to represent the perpendicular C E to the tangent at the initial point A, and c the initial velocity, it will be evident that when v becomes c, s becomes d; therefore $cd = C$, and the corrected integral will be $v \, . \, s = cd$.

The areas of all parallelograms circumscribing an ellipse formed by drawing tangents at the extremities of two conjugate diameters are constant, each being equal to the rectangle under the axes.

Take a to represent the semi-transverse axis, and b the semi-conjugate axis; P C, C D, Fig. 3348, two semi-conjugate diameters, $b \, . \, a = $ P P′ C D, $\frac{ba}{\text{CD}} = $ P P′.

3348.



The angles made by the focal distances with the tangent are equal and the angle at P is equal to the angle at E on account of the tangent being parallel to the diameter E D; therefore, by similar triangles, $y : s ::$ P E : P P′, $\frac{s \, . \, \text{PE}}{y} = $ P P′. If straight lines be drawn from the foci to a vertex of any diameter, the distance from the vertex to the intersection of the conjugate diameter with either focal distance is equal to the semi-transverse axis,

$$\mathrm{P\,E} = a, \frac{s\,.\,a}{y} = \mathrm{P\,P'}; \quad \frac{b\,.\,a}{\mathrm{C\,D}} = \mathrm{P\,P'} = \frac{s\,.\,a}{y}, \quad s = \frac{b\,.\,y}{\mathrm{C\,D}}.$$

The rectangle under the focal distances of the vertex of any diameter is equal to the square of the semi-conjugate diameter, $\mathrm{F\,P}\,.\,y = \mathrm{C\,D}^2$; but the focal distances are equal to the transverse axis, $\mathrm{F\,P} + y = 2a$, $\mathrm{F\,P} = (2a - y)$. Substituting value for F P, $(2a - y)\,.\,y = \mathrm{C\,D}^2$, $\sqrt{(2a - y)\,y} = \mathrm{C\,D}$. Substituting this value in $s = \frac{b\,.\,y}{\mathrm{C\,D}}$, we have $s = \frac{b\,.\,y}{\sqrt{\{(2a - y)\,y\}}}$. Substituting this value for s in the equation $v\,.\,s = c\,.\,d$, $v\,.\,\frac{b\,.\,y}{\sqrt{\{(2a - y)\,y\}}} = c\,d$, $v\,.\,b\,.\,y = c\,.\,d\,.\,\sqrt{\{(2a - y)\,y\}}$, $v^2.\,b^2.\,y^2 = c^2.\,d^2.\,(2a - y)\,y$, $v^2.\,b^2.\,y = c^2.\,d^2.\,(2a - y)$, $v^2 = \frac{c^2.\,d^2}{b^2}\;\frac{2a - y}{y}$. Differentiating, we obtain $-v\,.\,dv = \frac{c^2.\,d^2}{b^2}\cdot\frac{a\,.\,dy}{y^2}$; but $-f\,dy = v\,.\,dv$; $\therefore f\,dy = -v\,.\,dv$, $f\,dy = -v\,.\,dv = \frac{c^2.\,d^2}{b^2}\cdot\frac{a\,.\,dy}{y^2}$, $f = \frac{c^2.\,d^2.\,a}{b^2}\cdot\frac{1}{y^2}$. Take $\frac{c^2.\,d^2.\,a}{b^2} = \mathrm{A}$, $f = \frac{\mathrm{A}}{y^2}$, which shows that the force of attraction is inversely proportional to the square of the variable distance y of a particle moving in an elliptical orbit, the centre of the attracting force being in one of the foci. This therefore is the closest approximation to the law of attraction which has as yet been attained. The same law will be found to exist with reference to a body moving on the arc of a parabola, the centre of attraction being situated in the focus, which can be shown as follows;—

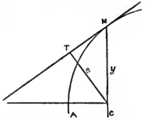
Let C, Fig. 3349, be the focus of the parabola A M: A the vertex. The perpendicular s to the tangent at the point M is a mean proportional between the distance y from the focus to that point, and the distance C A from the focus to the vertex. Take $\mathrm{C\,A} = a$, $a\,.\,y = s^2$, $\sqrt{a\,.\,y} = s$. Substituting this value for s in the equation $v\,s = c\,d$, we have $v\,.\,\sqrt{(a\,y)} = c\,.\,a$. A C is perpendicular to the tangent at the vertex; therefore $a = d$, $v\,.\,\sqrt{(a\,y)} = c\,.\,a$, $v^2 = \frac{c^2.\,a}{y}$. Differentiating,

$$v\,.\,dv = -\frac{c^2 a\,.\,dy}{2\,y^2}, \quad -v\,.\,dv = \frac{c^2 a\,.\,dy}{2\,y^2};$$

but $f.\,dy = -v\,.\,dv$, $f.\,dy = -v\,.\,dv = \frac{c^2 a\,.\,dy}{2\,y^2}$, $f = \frac{c^2.\,a}{2}\cdot\frac{1}{y^2}$.

Take $\frac{c^2 a}{2} = \mathrm{A}$, $f = \frac{\mathrm{A}}{y^2}$.

3349.



If the earth was perfectly spherical the directions of gravity would all concur at its centre. Therefore, considering the earth as a sphere and applying the laws of attraction founded upon astronomical observations, we might suppose that the force of gravity with reference to bodies near the surface of the earth acts upon lines tending towards such central point with an intensity varying inversely as the square of the distance from the centre of attraction. That this is the true law of attraction, so far as up to the present time human reason can recognize it, seems to be generally admitted by all writers upon the science of gunnery. But it seems to be thought that the working out of the problems involved in such a law in all their integrity, so as to bring them within the scope of practical utility, would require the command of a calculus more powerful than any we are at present in possession of. Therefore, in order to bring the subject within the grasp of comparatively easy calculation, we suppose;—

1st. That the lines of action of the force of gravity, instead of all tending to a common point at the centre of the earth, are all parallel to each other.

2nd. That within the space above the surface of the earth which we have to consider with reference to the motion of projectiles, we may dispense with a scrupulous adherence to the established laws of gravity.

In order to justify ourselves in these suppositions we endeavour to define the limits of error incurred as follows;—

And first as to the parallelism of the lines of action of the attractive force.

Taking the radius of the earth at 3·965, nearly, miles, 6978400 yds.; the length of one minute of a degree to such a radius would be over 2000 yds. A mile is only 1760 yds.; therefore within a lateral range of one mile the limit of error involved in considering the lines of attraction parallel instead of tending to a common point would be within one minute of a degree. As the centre of attraction is more and more removed from any points under consideration, the more will the lines of action of the attracting force tend towards parallelism. Consequently, considering the lines parallel is tantamount to considering the centre of attraction removed to an infinite distance.

We have assumed the distance of one mile as the lateral space necessary to consider with reference to the motion of projectiles, in our first supposition, and in the second we shall consider the same vertical distance as being far beyond the greatest height which can be reached by the trajectory of projectiles propelled by any human contrivance as yet discovered.

Taking the radius of the earth at 3965 miles, and assuming that the power of attraction is inversely proportional to the square of the distance from the centre, $(3\cdot966)^2 - (3\cdot965)^2$ will represent the difference in the intensity of the force at the surface of the earth and at a mile above it, $(3\cdot966)^2 - (3\cdot965)^2 = 7\cdot931$, $(3\cdot965)^2 = 15721000$, the thousandth part of which is 15721. The half of this is 7861. If therefore we take $f = (3\cdot965)^2$ as the representative of the attractive force at the surface of the earth, the difference in the intensity of the force at the surface and a point one mile above it may be expressed by the number 7931, which is very little in excess of $7\cdot861 = \frac{1}{2000} f$.

The supposition founded upon this reasoning is that we may assume the force of gravity (which is the name given to the attracting force) either as constant or as influenced by any law we please, or both, first one and then the other, for the vertical space of one mile above the surface of the earth; and that the limit of the error thus incurred will be the $\frac{1}{2000}$ part of the intensity of the force of attraction at the surface.

This mode of reasoning is very plausible, and would be conclusive if we had to deal with any of the palpable material subjects familiar to our daily experiences, for the $\frac{1}{2000}$ part of anything is in most cases a very small matter, and may be generally neglected without producing any sensible error in practice. But we have now to deal with a very subtle mysterious power, of the essence of which we know next to nothing; we approach those dark limits which circumscribe the action of the human intellect, and we ought therefore to feel our way very carefully as we proceed. So long as we have only to deal with ratios and comparisons, we are tolerably safe in drawing inferences, but we think it is very questionable whether we are justified in assuming that the neglect of the $\frac{1}{2000}$ part of the entire force of gravity at the surface of the earth will produce no sensible error in calculation, when at the same time we can form only a very vague conception of what the intensity of that force is, and if so, here at the very outset of our investigations is a most prolific source of error. Up to the present time, however, the subject has not been considered from this point of view; on the contrary, it has been taken as a fact, established by conclusive reasoning, that we may, within the limits assigned, assume almost any latitude in dealing with the force of gravity when applied to the theory of projectiles. And with this understanding we proceed to frame what are commonly called the laws of gravity.

Most people who have not closely considered the subject will be under the impression that there is no difficulty whatever in forming a perfectly clear and defined conception of the continued action of any given force. But when we come to analysis, reasoning, and calculation, we find that the only means we have of dealing with the matter is to consider that the force acts by successive impulses or solicitations, equal or otherwise, as the case may be, at the commencement or the end of very small equal intervals of time or of space measured on the line of action of the force.

If we take o to represent the small unit of time, and b the small unit of space, we must in the first place find an expression for the initial intensity of the force by supposing that it is such as to cause a particle of matter to move upon the line of action of the force through the space $A\,b$ during the unit of time o, or else that it is such as to cause the particle to move on the same line over the unit of space b during the time $A\,a$, the coefficient A being a quantity determined by experiment or otherwise. For instance, assuming the law which seems to be received as the true law of attraction, namely, that the intensity of the force varies inversely as the square of the distance from the centre of force, and supposing that during the first unit of time, which is usually taken at one second, d represents the distance passed over by a particle of matter, in consequence of the initial solicitation of the force, d^2 will evidently express the intensity of the force at the termination of the first second. If the particle were subject to the influence of this force alone, it would evidently descend during the next second, with a uniform velocity, a distance $= d^2$; but during its descent it is subjected to d^2 solicitations, each successively equal to the square of that immediately preceding it. The distance will therefore be expressed by $d^2 + d^{2.2} + d^{2.2.2} \ldots\ldots d^{d^2-2} + d^{d^2}$, a series, the exponents of the consecutive terms of which form a geometrical series of which the first term and the common ratio are 2 and the number of terms of the series d^2.

The expression for the distance corresponding to each of the succeeding seconds will evidently be a series of the same form, the last term of each series being taken for the first term, as well as for the number of terms of the succeeding series. The sum of all the series will express the distance actually descended in any given time, the time t expressing the number of series. If we should suppose the intensity of the attractive force to be inversely as the distance from the centre of force, taking d as before to represent the distance passed over during the first second, the intensity of the force at the end of the first second will evidently be represented by $2\,.\,d$; the particle of matter under the influence of this force alone would evidently descend a distance equal $2\,.\,d$, but during the descent it will be subjected to two solicitations of gravity each separately equal to d. Therefore at the end of the second second the force will be represented by $4\,.\,d$; at the end of the third second by $16\,.\,d$, &c. Therefore $d + 2^2.d + 2^{2.2}.d \ldots\ldots 2^{t-2}.d + 2^t.d$, a series of which the exponents of the coefficients of the terms form a geometrical series of which the first term and the common ratio are 2, and the number of terms t will express the distance descended by a particle of matter during the time t.

In framing the laws of gravity this latter supposition seems to have been to a certain extent adopted, for we are told that during the first second of descent d becomes $2\,d$, and is then called g. This is so far intelligible, but what follows is, to say the least of it, rather startling, and a little difficult to be understood, for d expires in giving birth to g, and this posthumous offspring is not only twice as big as his progenitor, but he appears to be endowed with the most extraordinary and supernatural powers, for he has a capability of generating a constantly increasing velocity, which ought to be simply an exponent of his own increase, but wonderful to relate, g never alters. He goes down to infinity for the purpose of settling some small matters relative to terminal velocity (of which we shall speak presently), and comes up again quite unchanged; he is employed to solve complicated problems with reference to variably accelerated or retarded velocity; he is blown up by gunpowder, forced into steam boilers, up and down funnels, through fire and water, but is not in the slightest degree affected by all these vicissitudes. Whenever we come across him we find him placidly and systematically doing his duty as the representative of the force of gravity—in all places and at all times the old familiar g, exactly as he appeared at his birth.

The fact of a heavy body being suspended in space without any support, and being in a state of rest, and then commencing suddenly to descend by the influence of an initial force which is equal to nothing, may be a conception easily formed in a well-trained mathematical mind, but to the uninitiated it is a little difficult of comprehension.

In order to illustrate as clearly as possible the method adopted of deducing the laws of gravity, we shall return to the language of the differential and integral calculus, taking again the expressions already established, $dv = f\,dt$, $ds = v.dt$, but supposing the generating power or force of gravity which is represented by f to be constant and invariable. Integrating $dv = f.dt$, we get $v = f.t$, $\frac{dv}{f} = dt = \frac{ds}{v}$, $v.dv = f.ds$; integrating $v^2 = 2.f.s$, $v = f.t$, $v^2 = f^2t^2$, $v^2 = 2fs$, $f^2t^2 = v^2 = 2fs$, $ft^2 = 2s$, $\frac{v}{t} = f = \frac{v^2}{2s}$, $2.s = vt$. From the equations thus established, we draw the following conclusions;—1st. From $v = f.t$ we assume that the velocity acquired by a body falling freely from a state of rest, and being acted upon by gravity alone, is proportional to the time elapsed. 2nd. From $v^2 = 2f.s$ we assume that the spaces described in the descent are proportional to the squares of the velocities; or by $ft^2 = 2.s$ to the squares of the times; or by $2.s = vt$ to the times and velocities conjointly.

Comparing the two equations, $s = t.v$ and $2.s = tv$, the first being referred to uniform velocity and the second being supposed to refer to accelerated velocity, the following inference is drawn. The space described uniformly with the velocity acquired by a body falling freely from a state of rest is double the space described by the body while generating such velocity. This is the foundation upon which a very complicated structure is raised, elaborate tables of reference are compiled, and the changes are rung upon all the various combinations of the quantities of space, time, and velocity, in all of which g plays his invariable part as the representative of gravity and unalterable sameness.

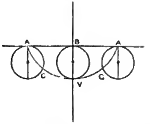
We have given the above few simple differential expressions as illustrating most easily the course followed in constructing the laws of gravity, but the matter is generally explained by a much more elaborate process. We shall now make a few remarks upon this mode of deducing the laws of gravity.

The effects of gravity are represented by supposing that the force acts by equal solicitations, at the end of equal intervals of time called seconds; it has been proved that the action of the force is inversely proportional to the square of the distance from the centre of attraction. It would therefore seem that the above supposition was as far from the truth as the parabolic curve is stated to be from the true trajectory of a projectile. The intensity of the initial solicitation of the force, and consequently its exponent velocity, are exhibited (upon the supposition that it may be considered constant within assigned limits) with reference to units of time and space as follows. The number of feet descended by a particle of matter during one second of time is in the first instance supposed to be ascertained by accurate experiments with the pendulum, &c. (and of the accuracy of these experiments we shall speak presently); this, which thus becomes a known quantity, is expressed by d. d is at first supposed to represent the value of each of the solicitations which are supposed to take place at the end of each succeeding second, for we find that at the end of the first second d becomes $2.d$, and is called g, which evidently represents the intensity of the force generated by or resulting from two successive solicitations. In accordance with this assumption, at the end of the second second, three equal solicitations would have taken place; and consequently the resulting force and its exponent velocity would be expressed by $3.d$. But it is not so; g is now taken to represent the value of the successive solicitations. Although we may have implicit faith in the accuracy of the experiment which introduced d to our notice, g evidently owes his existence to an arbitrary assumption which, although supposed to be admissible within assigned limits, is proved to be very far from the truth. I think, therefore, there is at least room for doubt whether g should be at once unhesitatingly recognized as the legitimate representative and successor of d. It would appear to be quite allowable to form a series according to a certain law, and having ascertained the value, reject the first term upon the supposition that the terms were so small individually that the neglect of one would in the aggregate produce no sensible error. But in the present instance we have not only done this, but we have altered the value of what ought to be the constant increment by substituting g for d. This little sin against fair logical reasoning is glossed over and concealed by ingenious illustrations and high-sounding terms specially framed and adapted for the confusion of useful knowledge; and it seems to be expected that the illegitimacy of g's birth will be condoned upon the ground of his being so very small; but we are afraid this sin against gravity, like all other sins, will be found to bear its fruits, and that something else besides the atmosphere is to be blamed, when we find our theory and practical experiences so very divergent.

The assumption that the spaces described by a falling body in its descent are proportional to the squares of the times is founded upon the supposition that we are justified in considering the generating power or force of gravity, which is represented by f in the expressions involving space, time, and velocity, as constant; but it seems absurd to suppose that we can separate the essence of anything from the exponent that marks its existence, and consider that one varies while the other does not. The laws of gravity now extant, whether fallible or infallible, are evidently dependent upon the accuracy of the experiment by means of which we are supposed to have ascertained the space described by a descending body during one second of time. We shall therefore now say a few words on this subject.

If the circumference of a circle be rolled on a right line, beginning at any point A, the movement being continued till the same point A arrives at the line again, making just one revolution, and thereby measuring out a straight line A B A, Fig. 3350, equal to the circumference of the circle, while the point A in the circumference traces out a curve line A G V C A; the curve thus traced is called the common cycloid; the line A A is called the base; V the vertex; V B the axis;

3350.



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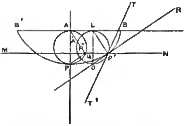
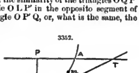
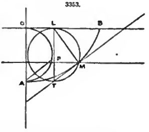


and the circle by the rotatory motion of which the curve is described, is called the generating circle. There are several properties belonging to the species of cycloidal curve called the common cycloid; but we shall only speak of those which immediately relate to the experiment under consideration. As the generating circle rolls along the base of the cycloid, the describing point has two motions; first a progressive motion in a direction parallel to the base B B′, Fig. 3351, and secondly, a motion of rotation round the centre of the generating circle. These motions are equal, for, in the time of one revolution of the generating circle, the describing point moves by its progressive motion through the space B B′, while by its motion of rotation it moves through a space equal to the circumference of the circle. Suppose the circle to roll from the position A in which the describing point P coincides with the vertex of the cycloid, to the position L in which the describing point has moved to P′, when the point which was at A will be now at A′; the distance L A will then be equal to the arc L A′ of the circle, since that arc has rolled over L A. The point P′, in consequence of the two equable motions already explained, one in the horizontal direction P′ N parallel to A B, and the other in the direction of the tangent to the generating circle P′ T at the point P′, will have an actual motion in a direction equally inclined to each of these lines. The direction of the curve at P′, or, what is the same, the direction of a tangent to the curve at that point, will therefore be represented by a line bisecting the angle N P′ T, and this line will be the continuation of the chord of the arc of the generating circle between P′ and the highest point O; for if L P′ be drawn the angle O P′ M will be equal to the angle O L P′, on account of the similarity of the triangles O Q P′ and O P′ L. The angle O P T′ will also be equal to the angle O L P′ in the opposite segment of the circle; therefore the angle O P′ T will be equal to the angle O P′ Q, or, what is the same, the angle N P′ R will be equal to the angle T P′ R. The line O P′ R therefore bisects the angle T P′ N, and is therefore a tangent to the cycloid at P′. Since the arcs A P″ and L P′ are equal, and also the arcs P P″ and O P′, the lines A P″ and L P′ are equal and parallel, and the lines P P″ and O P′ are likewise equal and parallel. The tangent at P′ is therefore parallel to the corresponding chord P″ P of the generating circle on the axis. The direction of motion in any point of a curve is always in the tangent at that point; consequently, if the motion with which any point *m*, Fig. 3352, arrives at M was to become uniform, the point *m* would proceed in the direction of the tangent T M, therefore the directions of the motion in the abscissa A P, ordinate P M, and curve being in the sub-tangent T P, ordinate P M, and tangent T M. The differentials of the abscissa, ordinate, and curve may be represented by the three sides of the triangle T P M, or by the corresponding sides of any similar triangle.

3352.



3353.



Draw M P, Fig. 3353, perpendicular to the diameter L T of the generating circle. Take L T = a, T P = x, the chord T M = p, and the arc A M = z.

$$\therefore\ \mathrm{TM} : \mathrm{TL} :: \mathrm{TP} : \mathrm{TM}, \quad p : a :: dx : dz.$$

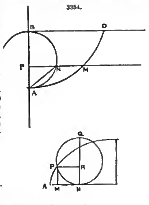
$$p \,.\, dz = a\, dx.$$

$$\mathrm{TL} : \mathrm{TM} :: \mathrm{TM} : \mathrm{TP}, \quad a : p :: p : x.$$

$$a x = p^2,\ a \,.\, dx = 2p \,.\, dp,\ p \,.\, dz = a \,.\, dx = 2p \,.\, dp,\ dz = 2\,dp,\ z = 2p.$$

Take a to represent the diameter B A, Fig. 3354, of the generating circle, and let A P = y. Upon the supposition that the lines of action of the gravitating force are parallel to the axis and perpendicular to the base of the cycloid, $dz : dy :: f : \frac{dy}{dz} f$. Substituting this value for f in the equation $dv = f\,dt$, $dv = \frac{dy}{dz}.f.dt$, $\frac{dv.dz}{f.dy} = dt = \frac{dz}{v}$, $v.dv = f.dy$; and because in this case v increases as y diminishes, $v.dv = -f.dy$. If we take d to represent the height fallen through in a second, we must, according to the conventional rule, take $2d$ to express the uniform velocity equal to the velocity generated by falling through the height d; therefore in the equation $v.dv = -f.dy$ we are told that we must substitute $2d$ for f in order to obtain the actual value of d in known terms. The equation therefore becomes $v.dv = -2d.dy$. But this is in reality nothing more than our old friend g, who seems to be always turning up, like the clown in a pantomime, in some new disguise, and it is only by treating him differentially that we can detect him. However, he is here engaged in fulfilling a sacred duty, for he is on his way to search for the remains of his deceased parent d, who it will be recollected disappeared in such a mysterious manner at the commencement of g's career. Integrating $v.dv = -2d.dy$, we get $v^2 = C - 4.d.y$. When $y = a$, $v = 0$; therefore $C = 4.a.d$, and the corrected integral is $v^2 = 4.a.d - 4.d.y$, $v = 2\sqrt{(a.d - d.y)}$.

3354.



Take p to represent the chord A N,

$$\text{A P : A N :: A N : A B}, \quad y : p :: p : a.$$

$$a.y = p^2, \ \sqrt{(a.y)} = p, \ z = 2.p, \ z = 2\sqrt{(a.y)}, \ dz = \frac{a.dy}{\sqrt{(a.y)}}.$$

Substituting the values just found for v and dz in the equation $dz = v.dt$, we get

$$\frac{a.dy}{\sqrt{(a.y)}} = 2\sqrt{(a.d - dy)}\,dt = 2\sqrt{\left\{a.d\left(1 - \frac{y}{a}\right)\right\}}\,dt.$$

Divide both sides of the equation by $2\sqrt{\left(1 - \frac{y}{a}\right)}$,

$$\frac{a.dy}{2\sqrt{(ay - y^2)}} = \sqrt{(a.d)}\,dt, \quad \int \frac{a.dy}{2\sqrt{(ay - y^2)}} = \sqrt{(a.d)}\,t = \text{versin.}^{-1}\,y$$

to diameter a. When $y = 0$, versin.$^{-1}\,y$ expresses ½ the circumference of the circle, and t the time of descent through half the cycloid. Take c to represent versin.$^{-1}\,0$ to diameter a, $c = t\,(a.d)$. Take $t = \frac{1}{2}''$, and consequently the time in the entire arc one second, $c = \frac{1}{2}\sqrt{(a.d)}$, $c^2 = \frac{1}{4}(a.d)$, $\frac{4\,c^2}{a} = d$; which may be put under the form $\frac{4\,c^2}{a^2}\,a = d$, $\frac{4\,c^2}{a^2} = \pi^2$, $\pi^2.a = d$.

Take A M $= x$, P M $= y$, Fig. 3354, Q N $= 2a$, arc N P $= \theta$,

$$x = \text{A M} = \text{A N} - \text{N M} = \theta - \sin.\,\theta = \text{versin.}^{-1}\,y - \sqrt{(2ay - y^2)},$$

the general expression for the normal is $y\sqrt{1 + \left(\frac{dy}{dx}\right)^2}$,

$$dx = \left\{\frac{a}{\sqrt{2ay - y^2}} - \frac{a - y}{\sqrt{2ay - y^2}}\right\} dy = \frac{y}{y^{\frac{1}{2}}\,(2a - y)^{\frac{1}{2}}}\,dy,$$

$$\frac{dx}{dy} = \frac{y^{\frac{1}{2}}}{(2a - y)^{\frac{1}{2}}}, \quad \frac{dy}{dx} = \frac{(2a - y)^{\frac{1}{2}}}{y^{\frac{1}{2}}}, \quad \left(\frac{dy}{dx}\right)^2 = \frac{2a - y}{y}, \quad 1 + \left(\frac{dy}{dx}\right)^2 = \frac{2a}{y},$$

$$\sqrt{\left\{1 + \left(\frac{dy}{dx}\right)^2\right\}} = \frac{(2a)^{\frac{1}{2}}}{y^{\frac{1}{2}}}, \quad y\sqrt{\left\{1 + \left(\frac{dy}{dx}\right)^2\right\}} = \sqrt{2ay}.$$

An expression for the radius of curvature is $\frac{(1 + p^2)^{\frac{3}{2}}}{q}$; when $p = \frac{dy}{dx}$ and $q = \frac{d^2y}{dx^2}$,

$$1 + p^2 = \frac{2a}{y}, \quad (1 + p^2)^{\frac{3}{2}} = \frac{(2a)^{\frac{3}{2}}}{y^{\frac{3}{2}}}, \quad \frac{dy}{dx} = \frac{(2a - y)^{\frac{1}{2}}}{y^{\frac{1}{2}}}.$$

Take $z = 2a - y$; $\frac{dy}{dx} = \frac{z^{\frac{1}{2}}}{y^{\frac{1}{2}}}$, $\frac{d^2y}{dx} = \frac{\frac{1}{2}\,y^{\frac{1}{2}}\,z^{-\frac{1}{2}}\,dz - \frac{1}{2}\,z^{\frac{1}{2}}\,y^{-\frac{1}{2}}\,dy}{y}$. But $dz = -dy$,

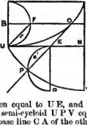
$$\frac{d^2 y}{d x} = \frac{-\frac{1}{2} y^{\frac{1}{2}} z^{-\frac{1}{2}} - \frac{1}{2} z^{\frac{1}{2}} y^{-\frac{1}{2}}}{y} d y = \frac{-\frac{y^{\frac{1}{2}}}{2 z^{\frac{1}{2}}} - \frac{z^{\frac{1}{2}}}{2 y^{\frac{1}{2}}}}{y} d y = -\frac{2 y + 2 z}{4 y z^{\frac{1}{2}} y^{\frac{1}{2}}} d y.$$

Substituting value for z, $\frac{d^2 y}{d x} = -\frac{2 y + 4 a - 2 y}{4 y (2 a - y)^{\frac{1}{2}} y^{\frac{1}{2}}} d y = -\frac{4 a}{4 y^{\frac{3}{2}} (2 a - y)^{\frac{1}{2}}} d y$; but

$d y = \frac{(2 a - y)^{\frac{1}{2}}}{y^{\frac{1}{2}}} d x$. Substituting this value for $d y$, $\frac{d^2 y}{d x} = -\frac{a}{y^2} d x$, $\frac{d^2 y}{d x^2} = -\frac{a}{y^2} = q$. Substituting these values, $\frac{(1 + p^2)^{\frac{3}{2}}}{q} = \frac{(2 a)^{\frac{3}{2}}}{y^{\frac{3}{2}}} \cdot \frac{y^2}{a} = 2^{\frac{3}{2}} a^{\frac{1}{2}} y^{\frac{1}{2}} = 2 \sqrt{2 a y}$. Taking R to represent the radius of curvature and N the normal, we have $R = 2 \sqrt{2 a y}$, $N = \sqrt{2 a y}$; therefore it is evident that in this curve the radius of curvature is equal to twice the normal; therefore at the vertex the radius of curvature is equal to twice the diameter of the generating circle.

The involute of a semi-cycloid A O U, Fig. 3355, is an equal semi-cycloid U P V in an opposite direction, the extremity of the base of the latter being in contact with the vertex of the former. From any point O draw O B parallel to A C, cutting the generating circle in F, and join F U; draw O P a tangent to the cycloid in O, and at E the point where it cuts the line U N, drawn from U, parallel to C A let fall E D perpendicular to U N and equal to C U. With E D as a diameter describe a circle intersecting the tangent O P in some point P. O E is equal and parallel to F U, p. 1749. O F is equal to the arc F *e* U. The circles C F U and D P E are equal by construction. The angles F U E, U E P are also equal, the chord being parallel to the tangent. The chords F U and E P are therefore equal, and as the angles they make with the common tangent to the circles at U and E are equal, the arcs F *e* U and P *n* E subtend equal angles, and are therefore equal. F O E U is a parallelogram, therefore U E is equal to F O. But F *e* U is equal to F O, therefore P *n* E is equal to U E. If the circle E P D had been placed on the line U N at U, and had rolled from U to E, the arc disengaged would have been equal to U E, and the point which was in contact with U would be at P in the periphery of a semi-cycloid U P V equal to A O U; the base line U N of the one being equal and parallel to the base line C A of the other; also the axis N V of the one equal and parallel to the axis C U of the other. And since the same may be shown to obtain with respect to any other point whatever in the arc A O U, the cycloid U P V is the involute of A O U.

3355.



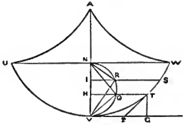
To construct a pendulum which shall oscillate in any given cycloid whose base is parallel to the horizon.—Let V N represent the axis of the cycloid and diameter of the generating circle. Produce V N till V A equals 2 . V N. Through A draw a line A C parallel to N U, the semi-base of the given cycloid; then on A C as a semi-base with axis A N describe a semi-cycloid A O U, and in like manner describe another semi-cycloid turned the contrary way. Then if a pendulum be suspended by a flexible string to the point A, the length of the string being exactly equal to the line A V or arc A O U, which from the nature of the curve are equal to each other, the pendulum oscillating in the plane of the cycloids will in its motion come alternately into contact with the cycloidal cheek A O U and the one corresponding to it on the opposite side of the line A V, and will describe the cycloid of which N V is the axis and N U the semi-base.

The length of a cycloidal pendulum vibrating seconds in any given latitude being ascertained, it will be evident that the diameter of the generating circle is also known, and therefore the quantity a in the equation $\pi^2 . a = d$ becomes a known quantity. The properties of the cycloid with reference to the vibrations of the pendulum are demonstrated upon the supposition that the whole mass of the pendulum is concentrated in a single point, but this cannot be assumed with reference to any vibrating body, for the centre of oscillation will not occupy the same place for any two points in the arc of vibration. This therefore in practice is a source of error.

Much time and trouble appear to have been expended in demonstrating the properties of the Isochrone. The name of this curve alone impresses one with a sort of reverence, and the investigations connected with the vibrations of pendulums and consequent determination of the force of gravity are highly interesting, and would no doubt have been found practically applicable, but for one slight drawback,—it was found that the exceedingly ingenious instrument by means of which the experiments were to be performed could not be made. The difficulties involved in the construction were so great that sufficient accuracy and durability could not be attained to render it practicably serviceable. All thoughts of making use of the cycloidal pendulum seem therefore to have been abandoned, and the theoretical demonstrations appear to have been placed on the same shelf with those well-known abstruse and ingenious investigations relative to the motion of projectiles in vacuo.

Having found out that the cycloidal pendulum would not do, we immediately turn to our old contrivance, based upon what ought now to be admitted as an axiom, namely, that all things which are very little are equal to each other, and that there is no difference to speak of between any of them. Upon the strength of this reasoning we invest the pendulum oscillating in a circular arc with all the properties of the cycloidal pendulum, upon the understanding that the arcs of vibration are to be very small. That we are justified in doing this is supposed to be proved as follows;—Let U V W, Fig. 3356, be the cycloid in which a body is supposed to oscillate, V N = N A, A U = A W = A V = $\frac{1}{2}$ U V W. The accelerating force in any point T of the curve has the same effect as if the body were placed upon the tangent T t; therefore the force of gravity is to the force in the direction T t as T t : T G, or by similar triangles as Q V : Q H, the tangent being parallel to the chord; or again, by similar triangles, as V N : V Q. In like manner, taking any other point S in the curve, the force of gravity is to the force in the curve as

3356.



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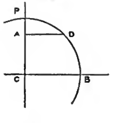


V R : V I or V N : V R. Therefore the accelerative force at different points T . S of the curve varies as the corresponding chords V Q . V R of the generating circle, or as the portions V T . V S of the curve measuring from the vertex, such portions of the curve being respectively double the corresponding chords. Therefore a body moving in a cycloidal arc is attracted by a force which varies directly as its distance from the lowest point V. We have therefore now to find expressions for the velocity and time under these circumstances. Let P, Fig. 3357, be the point from which a particle of matter commences its motion; take P C = a, its distance from the centre of force; let v = the velocity at any variable distance, A C = s, and take f to represent the force at some given distance l from C, compared with a unit of force which we will represent by m. As the intensity of the attractive force is directly proportional to the distance from the centre of force, $l : s :: f : \frac{f s}{l}$; therefore $\frac{f s}{l}$ is an expression for the force at the variable distance s compared with unity, and $\frac{m . f . s}{l}$ when measured by m. Substituting this value for f in the equation $v . d v = f . d s$, we have $v . d v = \frac{m f}{l} s . d s$; or, since v increases as s diminishes, $v . d v = -\frac{m f}{l} s . d s$. Integrating, $v^2 = -\frac{m f}{l} s^2 + \mathrm{C}$. When $v = 0$, $s = a$; $0 = -\frac{m f}{l} s^2 + \mathrm{C}$; $\mathrm{C} = \frac{m f}{l} a^2$. The corrected integral is therefore $v^2 = \frac{m . f}{l}\{a^2 - s^2\}$, $v = \sqrt{\left\{\frac{m f}{l}(a^2 - s^2)\right\}}$. In the quadrant P D B described from centre C with radius C P, the ordinate A D $= \sqrt{(\mathrm{C P}^2 - \mathrm{C A}^2)} = \sqrt{(a^2 - s^2)}$; therefore $v = \mathrm{A D}\sqrt{\frac{m f}{l}}$, from which we deduce the following;—The velocity corresponding to any space P A is proportional to the sine A D of the arc answering to the versed sine P A to radius C P.

To find an expression for the time.—Taking the expression $d s = v . d t$, which, as the velocity increases as the space diminishes, becomes $-d s = v . d t$, $-\frac{d s}{v} = d t = \sqrt{\frac{l}{m . f}}\,\frac{-d s}{\sqrt{(a^2 - s^2)}}$.

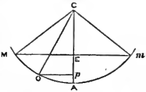
Take z to represent the arc P D,

$$\sin. s : \mathrm{R} :: d . \cos. z : d s, \qquad \frac{-d s}{\sqrt{(a^2 - s^2)}} = \frac{d z}{a}.$$
$$\sqrt{(a^2 - s^2)} : a :: -d s : d z.$$

Therefore $d t = \frac{d z}{a} . \sqrt{\frac{l}{m . f}}$. Integrating, $t = \frac{z}{a}\sqrt{\frac{l}{m . f}} = \frac{\mathrm{P D}}{\mathrm{P C}}\sqrt{\frac{l}{m . f}}$; for when $t = 0$, $z = 0$; when A C = 0, $t = \frac{\mathrm{P D B}}{\mathrm{P C}}\sqrt{\frac{l}{m . f}} = \frac{1}{2}\pi\sqrt{\frac{l}{m . f}}$. This is therefore an expression for the time in a semi-cycloidal arc, and $\pi\sqrt{\frac{l}{m . f}}$ for the full arc of vibration. l being the length of the semi-arc of vibration, and consequently the length of the pendulum; f being the representative of the force at a given distance l from the centre of force, and m being the representative of the unit of force, $\sqrt{\frac{l}{m . f}}$ is assumed as constant, the coefficient $\frac{1}{2}\pi$ is also constant; therefore t is constant for all the variable arcs represented by s. And this is supposed to prove the isochronism of vibration in the curve. $m f$ expresses the intensity of force at the vertical point of the curve, which causes the pendulum to descend along the curve estimated at a distance from the centre of force = l, the length of the line of descent; but when referred to the descent through the length of the pendulum from the point of vibration to the vertex, we must call it $2f$, according to the conventional rule, therefore the time of vibration $= \pi \frac{l}{2f}$.

We shall now find an expression for the time in the arc of vibration of the circular pendulum, in order to compare it with the expression first found, and thus ascertain the limit of the error involved in substituting the circular for the cycloidal pendulum. But we are sorry to say that $m.f$ will turn out to be our old friend g in a perfectly new disguise, for there is something mean in his insinuating himself into an experiment intended to test his own value.

3358.



Let M A m, Fig. 3358, be the circular arc in which a pendulum oscillates. Take the radius or length of the pendulum C M $= l$, A E $= b$, A $p = x$, $p.o = y$, and the variable arc $= s$. The velocity acquired by falling through the arc M o is equal to the velocity due to the vertical distance E p. Taking the equation $2fs = v^2$, we have $\surd(2f.s) = v$. Substituting E $p = (b - x)$ for s, $\surd\{2f(b-x)\} = v$; but $ds = v.dt$, $\frac{ds}{v} = dt$. Substituting value for v, $\frac{ds}{\surd\{2f(b-x)\}} = dt$.

The differential of an arc of a curve considered as a function of the ordinates of its extremities is expressed by $ds = \surd(dy^2 + dx^2)$; in the present case $y = (2lx - x^2)^{\frac{1}{2}}$,

$$dy = \tfrac{1}{2}(2lx - x^2)^{-\frac{1}{2}}.d(2lx - x^2),\ d(2lx - x^2) = 2l.dx - 2x\,dx = (l-x)2\,dx,$$

$$dy = \tfrac{1}{2}(2lx - x^2)^{-\frac{1}{2}}(l-x)2\,dx = \frac{(l-x)\,dx}{\surd(2lx - x^2)},\ dy^2 = \frac{(l-x)^2.dx^2}{(2lx - x^2)},$$

$$dy^2 + dx^2 = \frac{(l-x)^2\,dx^2}{(2lx - x^2)} + dx^2 = \frac{(l-x)^2 + (2lx - x^2)}{(2lx - x^2)}dx^2 = \frac{l^2 - 2lx + x^2 + 2lx - x^2}{(2lx - x^2)}dx^2$$

$$= \frac{l^2.dx^2}{(2lx - x^2)},\ \surd(dy^2 + dx^2) = \frac{l.dx}{\surd(2lx - x^2)},\ ds = \frac{l.dx}{\surd(2lx - x^2)};$$

and because s diminishes as the time augments, $ds = \frac{-l\,dx}{\surd(2lx - x^2)}$. Substituting this value in the equation $\frac{ds}{\surd 2f(b-x)} = dt$, $\frac{-l.dx}{\surd\{(2lx - x^2).2f(b-x)\}} = dt$. In order to obtain an expression for the time it only remains to integrate the first term of the above equation,

$$\frac{-l.dx}{\surd\{2f(b-x).(2lx - x^2)\}},\ (b-x)x = b.x - x^2,\ \frac{2lx - x^2}{x} = 2l - x.$$

Therefore the expression becomes

$$\frac{l}{\surd 2f}\,\frac{-dx}{\surd(bx - x^2)(2l - x)} = \frac{l}{\surd 2f}\,\frac{-dx}{\surd(bx - x^2)}(2l - x)^{-\frac{1}{2}},$$

$$(2l - x)^{-\frac{1}{2}} = 2l^{-\frac{1}{2}}\left(1 - \frac{x}{2l}\right)^{-\frac{1}{2}} = 2l^{-\frac{1}{2}}\left\{1 + \frac{1}{2}\,\frac{x}{2l} + \frac{1.3}{2.4}\,\frac{x^2}{4l^2} + \frac{1.3.5}{2.4.6}\,\frac{x^3}{8l^3}\dots\right\},$$

$$\frac{-l.dx}{\surd 2f(b-x).(2lx - x^2)} = \frac{1}{2}\sqrt{\frac{l}{2f}}\cdot\frac{-dx}{\surd(bx - x^2)}\left\{1 + \frac{1}{2}\,\frac{x}{2l} + \frac{1.3}{2.4}\cdot\frac{x^2}{4l^2}\dots\right\}.$$

The question therefore resolves itself into the integration of a series of terms of the form $\frac{x^n.dx}{\surd(bx - x^2)}$, which, taking $b = 2a$, becomes $\frac{x^n.dx}{\surd(2ax - x^2)}$.

$$\int\frac{dx}{\surd(2ax - x^2)} = \frac{1}{a}.\text{versin.}^{-1}\,x \text{ to radius } a.$$

$$\int\frac{x.dx}{\surd(2ax - x^2)} = \int\frac{a.dx - x\,dx}{\surd(2ax - x^2)} + a\int\frac{dx}{\surd(2ax - x^2)} = \surd(2ax - x^2) + a\int\frac{dx}{\surd(2ax - x^2)},$$

$$\int\frac{x^2\,dx}{\surd(2ax - x^2)} = \int x^{\frac{3}{2}}(2a - x)^{-\frac{1}{2}}dx = 2x^{\frac{3}{2}}.\surd(2a - x) + 3\int x^{\frac{1}{2}}.\surd(2a - x)\,dx,$$

but $x^{\frac{1}{2}}\surd(2a - x)\,dx$.

Multiply and divide by $x^{\frac{1}{2}}(2a - x)^{\frac{1}{2}} = \frac{2.a.x.dx}{\surd(2ax - x^2)} - \frac{x^2\,dx}{\surd(2ax - x^2)}$,

$$\int \frac{x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}} = 2\,x\,(2\,a\,x - x^2) + 3\,.\,2\,.\,a \int \frac{x\,d\,x}{\sqrt{(2\,a\,x - x^2)}} - 3 \int \frac{x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$4 \int \frac{x^2\,d\,x}{\sqrt{(2\,a\,x - x^2)}} = 2\,x\,(2\,a\,x - x^2) + 3\,.\,2\,.\,a \int \frac{x\,.\,d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$\int \frac{x^2\,d\,x}{\sqrt{(2\,a\,x - x^2)}} = \tfrac{1}{2}\,x\,(2\,a\,x - x^2) + \frac{3\,.\,2\,.\,a}{4} \int \frac{x\,d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$\int \frac{x^3 . d\,x}{\sqrt{(2\,a\,x - x^2)}} = \int x^{\frac{5}{2}} . (2\,a - x)^{-\frac{1}{2}} . d\,x = 2\,x^{\frac{5}{2}} \sqrt{(2\,a - x)} + 5 . \int x^{\frac{3}{2}} \sqrt{(2\,a - x)}\,d\,x,$$

$$\text{but} \quad x^{\frac{3}{2}} \sqrt{(2\,a - x)}\,d\,x.$$

Multiply and divide by $x^{\frac{1}{2}} \sqrt{(2\,a - x)} = \dfrac{2\,a\,x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}} - \dfrac{x^3\,d\,x}{\sqrt{(2\,a\,x - x^2)}}$,

$$\int \frac{x^3\,d\,x}{\sqrt{(2\,a\,x - x^2)}} = 2\,x^2 \sqrt{(2\,a\,x - x^2)} + 5\,.\,2\,.\,a \int \frac{x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}} - 5 \int \frac{x^3 . d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$6 \int \frac{x^3 . d\,x}{\sqrt{(2\,a\,x - x^2)}} = 2\,x^2 \sqrt{(2\,a\,x - x^2)} + 5\,.\,2\,.\,a \int \frac{x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$\int \frac{x^3 . d\,x}{\sqrt{(2\,a\,x - x^2)}} = \tfrac{1}{3}\,x^2 \sqrt{(2\,a\,x - x^2)} + \frac{5\,.\,2\,.\,a}{6} \int \frac{x^2 . d\,x}{\sqrt{(2\,a\,x - x^2)}}.$$

We find therefore that

$$\int \frac{d\,x}{\sqrt{(2\,a\,x - x^2)}} = \frac{1}{a} . \text{ versin.}^{-1}\,x \text{ to radius } a, \qquad \int \frac{x\,d\,x}{\sqrt{(2\,a\,x - x^2)}} = \sqrt{(2\,a\,x - x^2)} + a \int \frac{d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$\int \frac{x^2\,d\,x}{\sqrt{(2\,a\,x - x^2)}} = \tfrac{1}{2}\,x\,(2\,a\,x - x^2) + \frac{3\,.\,2\,.\,a}{4} \int \frac{x\,.\,d\,x}{\sqrt{(2\,a\,x - x^2)}},$$

$$\int \frac{x^3 . d\,x}{\sqrt{(2\,a\,x - x^2)}} = \tfrac{1}{3}\,x^2 \sqrt{(2\,a\,x - x^2)} + \frac{5\,.\,2\,.\,a}{6} \int \frac{x^2\,d\,x}{\sqrt{(2\,a\,x - x^2)}}.$$

This will be sufficient to show the law of the series, and substituting b for $2\,a$, we have

$$\int \frac{d\,x}{\sqrt{(b\,x - x^2)}} = \frac{2}{b} \text{ versin.}_{-1}\,x \text{ to radius } \frac{b}{2}, \qquad \int \frac{x\,d\,x}{\sqrt{(b\,x - x^2)}} = \sqrt{(b\,x - x^2)} + \frac{b}{2} \int \frac{d\,x}{\sqrt{(b\,x - x^2)}},$$

$$\int \frac{x^2\,d\,x}{\sqrt{(b\,x - x^2)}} = \tfrac{1}{2}\,x\,(b\,x - x^2) + \frac{3\,.\,b}{4} \int \frac{x\,d\,x}{\sqrt{(b\,x - x^2)}},$$

$$\int \frac{x^3\,d\,x}{\sqrt{(b\,x - x^2)}} = \tfrac{1}{3}\,x^2 \sqrt{(b\,x - x^2)} + \frac{5\,.\,b}{6} \int \frac{x^2\,d\,x}{\sqrt{(b\,x - x^2)}}.$$

It will be evident that at the commencement of the arc of vibration the time must equal 0, therefore when $x = b$, $\displaystyle\int \frac{d\,x}{\sqrt{(b\,x - x^2)}} = \pi$, for R − cos. = versin., cos. 180° = − 1.

$$\begin{array}{rl} \text{R} & = 1 \\ \text{cos. } 180 & = \underline{-\,1} \\ & \,2 = \text{versin. } 180^\circ. \end{array}$$

$$\frac{2}{b} \text{ versin.}^{-1}\,b \text{ to radius } \frac{b}{2} = \pi,$$

$$\int \frac{x\,d\,x}{\sqrt{(b\,x - x^2)}} = \frac{1\,.\,b}{2}\,\pi, \qquad \int \frac{x^2\,d\,x}{\sqrt{(b\,x - x^2)}} = \frac{1\,.\,3\,.\,b^2}{2\,.\,4}\,\pi, \qquad \int \frac{x^3\,d\,x}{\sqrt{(b\,x - x^2)}} = \frac{1\,.\,3\,.\,5\,b^3}{2\,.\,4\,.\,6}\,\pi.$$

It will be evident that when $x = b$ all terms containing $(b\,x - x^2)$ as a factor vanish.

It will therefore be evident that integrating between $x = b$ and $x = 0$, and substituting the values of the above integrals in the series, $\frac{1}{2}\sqrt{\frac{l}{2f}}\,\frac{-dx}{\sqrt{(bx - x^2)}}\left\{1 + \frac{1}{2}\,\frac{x}{2l} + \frac{1.3}{2.4}\cdot\frac{x^2}{4l^2}\ldots\right\}$, we get $t = \frac{1}{2}\pi\sqrt{\frac{l}{2f}}\left\{1 + \frac{1^2}{2^2}\cdot\frac{b}{2l} + \frac{1^2.3^2}{2^2.4^2}\cdot\frac{b^2}{4l^2} + \frac{1^2.3^2.5^2}{2^2.4^2.6^2}\cdot\frac{b^3}{8l^3}\ldots\right\}$. This expresses the time of descent through half the arc of vibration, but with the velocity acquired during the descent the pendulum would proceed along an equal branch of the curve, its velocity being supposed to be extinguished after a lapse of time equal to the time of descent; therefore the time of a complete vibration will be expressed by $t = \pi\sqrt{\frac{l}{2f}}\left\{1 + \frac{1^2}{2^2}\cdot\frac{b}{2l} + \frac{1^2.3^2}{2^2.4^2}\,\frac{b^2}{4l^2} + \frac{1^2.3^2.5^2}{2^2.4^2.6^2}\cdot\frac{b^3}{8l^3}\ldots\right\}$. Therefore, upon the supposition that the time of vibration in the cycloidal arc is expressed by $t = \pi.\sqrt{\frac{l}{2f}}$, it will appear that the error incurred by substituting the circular for the cycloidal pendulum is expressed by a series of the powers of the versin. of the same angular value as the arc of vibration, having unity for its radius. It is argued that as the versines of small angles are exceedingly minute, the series will converge rapidly, and the error may be neglected in practice; or at least all the terms but the first or second may be neglected, and corrections applied accordingly. Assuming therefore that the circular pendulum may be substituted for the cycloidal pendulum, without producing sensible error, and taking the equation $\pi^2.a = d$, $3{\cdot}14159^2 = \pi^2 = 9{\cdot}8696$, $9{\cdot}8696\,a = d$. It has been found by experiment that the length of a pendulum vibrating seconds in the latitude of London $= 39{\cdot}125$. The length of the cycloidal pendulum is equal to twice the diameter of the generating circle, therefore $39{\cdot}125 = 2\,.\,a$, $19{\cdot}562 = a$, $9{\cdot}8696 \times 19{\cdot}562 = 193{\cdot}0623$, $193{\cdot}0623$ in. $= 16{\cdot}088$ ft. It will therefore be evident that the value given to d, from which the value of g is supposed to be derived, depends upon the length of a pendulum vibrating seconds in a particular latitude, in a circular arc which is assumed to be a cycloidal arc, because it is very small, and this is to be ascertained by experiment. This is the experiment which is generally mysteriously alluded to in the following words;—

"It has been ascertained by accurate experiments with the pendulum and by other means, that in the latitude of London a heavy body falling freely from a state of rest will describe a space of $16\frac{1}{12}$ ft. during the first second of the descent, and will have generated a velocity of $32\frac{1}{6}$ ft. a second," &c., &c.

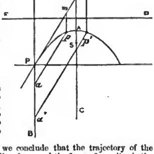
The method of determining the space descended during one second, said to have been suggested by Galileo by means of experiments with reference to the descent of bodies upon inclined planes, in consequence of the friction on the planes lead to no practically useful results.

The experiments made by means of Atwood's machine, a description of which will be found p. 7, are not sufficiently accurate for practical purposes.

We have gone into detail with reference to the apparent mixture of reasoning and arbitrary assumption upon which the laws of gravity seem to be founded, for it is upon the validity of these laws that the whole theory of gunnery as it now stands depends. If there is a flaw in this line of argument we should fail in arriving at practically useful results, even though we should be successful in determining accurately the law of resistance of the air to a body moving through it, to which point alone attention appears to be at present directed. We shall now exhibit as shortly as possible the most important of the principles which are supposed to constitute the present system of gunnery.

If a body be projected with a given velocity in a given direction from any given point of departure, it is considered that the body, if uninfluenced by any disturbing force, will proceed continually in the given direction with a uniform velocity equal to the initial velocity originally impressed upon it. The velocity being uniform, the spaces described on the line of direction will be proportional to the times. According to the conventional rule, the spaces described by a heavy body subject to the attractive force of gravity upon a line perpendicular to the horizon are proportional to the squares of the times. Admitting the above statements as true, and combining them together, we are in a position to define the curve of trajectory.

3359.



Amongst the properties of the common parabola we find the following;—1. The ordinates to all diameters are parallel to the tangent at the vertex. 2. The abscisses are proportional to the squares of the semi-ordinates.

If therefore we take P B a diameter of any parabola, of which A, Fig. 3359, is the vertex, A C the axis, F D the directrix, s the focus, $ap^2 : a'p'^2 :: \mathrm{P}a : \mathrm{P}a'$; and completing the parallelograms we have

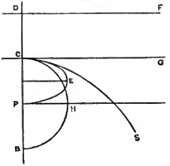
$$\mathrm{P}m^2 : \mathrm{P}m'^2 :: mp : mp.$$

If therefore we take Pm and Pm' to represent the spaces which would be described with a uniform velocity on the tangential line during any given times of the transit t and t', mp and $m'p'$ will evidently represent the spaces due to the action of gravity during the same time; therefore p and p' will represent the position of the projectile at the end of the times t and t', and as this will hold good for all distances which may be assumed on the tangential line, we conclude that the trajectory of the projectile, when subject only to the influence of the propelling force and the force of gravity, is the parabolic curve.

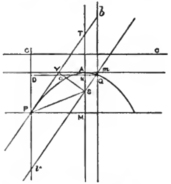
According to the laws of gravity, a body in its descent through any vertical distance will generate a velocity which, acting uniformly, would cause the same body to describe a distance equal to double the space descended in a time equal to the time of descent. The height due to any velocity is therefore taken as the exponent or measure of the initial velocity equal to the velocity generated.

Take the vertical line C P to represent the height due to any given initial velocity. The horizontal line C G, Fig. 3360, through the point C at right angles to the line C P will be the directrix; the semicircle C H B described with radius C P from centre P will be the locus of the foci; and the semi-ellipse C E P upon C P as conjugate axis, and of which the transverse is double the conjugate, the locus of the vertices of all the parabolæ representing the trajectories of a projectile impressed with the given initial velocity at the point P whatever may be the original direction given to the projectile. And, lastly, the parabolic curve C S described with focus P, and directrix D F, vertex C, will be the locus of the extremities of the greatest ranges attained with the given initial velocity. These points are proved as follows:—

3360.



3361.



1. The horizontal line C G through the point C will be the directrix. Take P b, Fig. 3361, to represent the tangential line of direction P v equal to C P, and complete the parallelogram P b . Q v, $CP = Pv = bQ$: therefore P b represents the space described in the tangential direction with a uniform velocity equal the initial velocity impressed in the time during which the initial velocity has been generated by the descent through $CP = bQ$. Therefore, according to the conventional rule, $Pb = 2\,CP$, $Qv = 2\,Pv$, $Qv^2 = 4\,Pv^2 = 4\,Pv.CP$, $\frac{Qv^2}{4\,Pv} = CP$. Take P A Q to represent the curve of trajectory corresponding to the tangential direction P b, S the focus, A the vertex. Let S Y be a perpendicular to the tangent P b, and join S P. It will be evident that if it can be shown that S P is equal to C P (for which we have already obtained an expression), the proposition will be proved, as the perpendicular from the point P in the curve upon the horizontal line C G will be equal to the distance of the same point P from the focus, which is a property of the parabolic curve.

The tangent at the vertex A is perpendicular to the axis A M, and the perpendicular from the focus S upon the tangent at the point P is a mean proportional between S P and S A; therefore the right-angled triangles S P Y and S A Y are similar.

The right-angled triangles S A Y . S m Y are similar, having a common angle at Y. The right-angled triangles S m Y . S Q O are similar, having a common angle at S. The right-angled triangles S Q O . Q D v are similar, having a common angle at Q; therefore the triangles S P Y and Q D v are similar, and $Qv^2 : QD^2 :: SP^2 : SY^2$; but $SY^2 = SP.SA$, $\therefore Qv^2 : QD^2 :: SP : SA$.

The right-angled triangles Q D v and P M T are similar, the opposite angles v and T in the parallelogram P v T S being equal, therefore

$$\begin{aligned} QD : De &:: PM : MT \\ &:: PM^2 : PM.MT. \end{aligned}$$

Substituting $4\,AS.AM$ for PM^2, and $2\,AM$ for MT, we have

$$\begin{aligned} QD : Dv &:: 4\,AS.AM : PM.2\,AM \\ &:: 4\,AS : 2\,PM; \end{aligned}$$

therefore $4\,AS.Dv = 2\,PM.QD$, $PM^2 = 4\,AS.AM$, $QN^2 = 4\,AS.AN$.

$$PM^2 - QN^2 = 4\,AS.AM - 4\,AS.AN = 4\,AS(AM - AN) = 4\,AS.MN = 4\,AS.DP,$$

$$PM^2 - QN^2 = (PM + QN)(PM - QN), \text{ but } PM + QN = QD;$$

$$\therefore PM^2 - QN^2 = (PM - QN)\,QD.$$

$$4\,AS.DP = PM^2 - QN^2 = (PM - QN)\,QD, \quad 4\,AS.DP = (PM - QN)\,QD.$$

Subtracting this equation from the equation $4\,AS.Dv = 2\,PM.QD$,

$$\begin{array}{c} 4\,AS.Dv = 2\,PM.QD \\ 4\,AS.DP = (PM - QN)QD \\ \hline 4\,AS.Pv = (PM + QN)QD = QD^2 \\ 4\,AS.Pv = QD^2. \end{array}$$

Substituting this value for QD^2 in the proportion $Qv^2 : QD^2 :: SP : SA$, we have

$$Qv^2 : 4\,AS.Pv :: SP : AS,\ \ Qv^2 = 4\,SP.Pr,\ \ \frac{Qv^2}{4\,Pv} = SP,\ \ CP = \frac{Qv^2}{4\,Pv} = SP:$$

therefore $CP = SP$, and consequently the line CG is the directrix of the parabola; and as this will hold good whatever direction the tangential line P*b* may take, the proposition is proved.

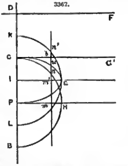
2. The semicircle C H B described with radius C B from centre P will be the locus of the foci. This follows as a corollary to the former proposition; for the foci being always at a distance from the point P in the curve equal to the perpendicular upon the directrix from the same point, the foci must necessarily lie in the periphery of the semicircle described with P as a centre and C P as radius.

3. The semi-ellipse C E P, Fig. 3362, upon C P as conjugate axis, and of which the transverse is double the conjugate, is the locus of the vertices; bisect C P in I, with I as centre and a distance equal C P as radius describe the semicircle K E L. $m'v : m'n' :: IC : IE :: 1 : 2$, $m'n' = 2\,m'r$, $\therefore m'v = vn'$, $mn = m'a'$, $mm' = m'b$, $\therefore m'a = bn'$, $m'v - m'a = va' - bn'$, $av = vb$; and as CG is the directrix and a the focus, *v* must evidently be the vertex; and as this will hold good for any other point in the periphery of the semicircle C H B, which may be assumed as the focus of the curve of trajectory, the proposition is proved.

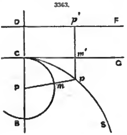
4. The parabolic curve C S, Fig. 3363, described with focus P and directrix D F, vertex C, will be the locus of the extremities of the greatest ranges attained with the given initial velocity.

It has been already shown that the semicircle C *m* B described with C P as radius and P as centre is the locus of the foci of all the parabolæ representing the trajectory of a projectile discharged from the point P with the initial velocity represented by the descent through C P.

3362.



3363.



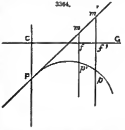
Let *m* be the focus of any one of these parabolæ; join P*m*, and produce the connecting line to meet the parabola C S in *p*, and draw pp' perpendicular to D F; then, as D F is the directrix and P the focus of the parabola C S, $Pp = pp'$; but $Pm = PC = CD = p'm'$; therefore

$$Pp - pm = pp' - p'm',\quad mp = pm'.$$

Therefore, as it has been shown that CG is the directrix of the parabola of which *m* is the focus, *p* must be a point in the curve of that parabola; and since the tangent of such parabola as well as the tangent of the parabola C S at the common point *p* bisect the same angle Ppp', they must coincide. Consequently the two parabolæ having a common tangent at the point *p* touch each other at that point; and as this is true for every point in the semicircle C*m*B, it follows that the curves of all the trajectories of a projectile discharged with the given velocity from the point P will touch the concavity of the parabola C S, and lie wholly within it. No point without the parabola C S can be struck while the initial velocity remains unchanged; for if the elevation be increased, the focus of the parabola which the body would describe will be on the portion C*m* of the circumference of the semicircle C*m*B, and the trajectory will touch the parabola C S in some point between C and *p*, and being wholly within the parabola C S, it must intersect the line P*p* in some point nearer to the initial point P than *p*. If the elevation be diminished, the curve of trajectory will touch the parabola C S in some point below *p*, and will therefore intersect P*p* in some point nearer to P than *p*.

The times of describing any given portions $Pp.pp'$ of the curve are as the corresponding parts $Pm.mm'$, Fig. 3364, of the tangent or the intercepted parts $Cf.ff'$ of the directrix; for according to the original supposition $t.Pp = t.Pm$ and $tpp' = tmm'$; and because the directrix cuts the three parallels $PC.pm.p'm'$, $Pm : mm' :: Cf : ff'$. So far the subject may be most clearly illustrated under the form of geometrical reasoning; but in order to deduce practical formulæ adapted to actual calculation and comparison, we must again avail ourselves of the facilities afforded by the rudimental portion of the differential and integral calculus; for independently of the necessity of constructing algebraical formulæ adapted to practical purposes, a

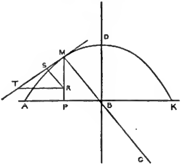
3364.



process of reasoning and a consequent result can be thus exhibited under the form of a few well-known symbols, which would require pages of geometrical reasoning to demonstrate.

Take the parabolic curve A D K, Fig. 3365, of which A K is the base and D B the axis, to represent the trajectory of a shot discharged from the point A with a given initial velocity. Let the ordinate M P be perpendicular to the horizontal base A K, M T a tangent to the curve at the point M. Take M P = y, A P = x, and A the origin of the co-ordinates. From any point R in the ordinate M P draw the perpendicular R S to the tangent M T; draw R T perpendicular to the ordinate to meet the tangent in T, the triangle M T R may be taken to represent the differential triangle. Then the force f in the direction M P is to the effect in the direction R S perpendicular to the tangent as M R : R S; or, by similar triangles, as M T : T R :: $dz : dx$; therefore $\frac{dx}{dz} f$ will express the force in a direction perpendicular to the tangent. Take C M to represent the radius of curvature at the point M, and let C M = r; then, as C M : M T as the differential of the circular arc described with C M as radius is to the differential of the circular arc described with M T as radius, we have $r : dz :: dz : \frac{dz^2}{r}$; but the differential of the arc described with M T as radius may be taken as representing the second differential of the arc described with C M as radius; we may therefore assume $d^2 z = \frac{dz^2}{r}$. Taking the original equations $dv = f\,dt$,

3365.



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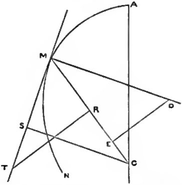

$dz = v\,.\,dt$, differentiating the last expression upon the supposition that dt is constant, we get $d^2 z = dv\,.\,dt$; substituting value for dv, $d^2 z = f\,.\,dt^2$, and substituting value for f, so as to render the expression applicable to the present case, $d^2 z = \frac{dx}{dz} f\,dt^2$, $\frac{dx}{dz} f\,dt^2 = d^2 z = \frac{dz^2}{r}$, $dx\,f\,dt^2 = \frac{dz}{r}$, $dz = v\,dt$, $dz^2 = v^2 dt^2$; therefore $f\,dx\,r = v^2 dz$. We shall now find a value for r applicable to the present case. Take D M = r the radius of curvature at the point M of the curve A M N, Fig. 3366, M T the tangent at the same point, C M the radius vector = y, C S a perpendicular upon the tangent from the centre C = S; the lines s and r will evidently remain parallel for every point in the curve. Take dz to represent the differential of the circular arc described with radius r, and ds the differential of the circular arc described with radius M S; D M : M S :: $dz : ds$. Take M T R to represent the differential triangle, M S : M C :: M R : M T. Therefore we have r : M S :: $dz : ds$, M S : $y :: dy : dz$. Compounding, $r : y :: dy : ds$, $r\,.\,ds = y\,.\,dy$, $\frac{r}{dy} = \frac{y}{ds}$; T M : T R :: C M : C S, $dz : dx :: y : s$, $dz\,.\,s = dx\,.\,y$. Considering the lines of attraction parallel is equivalent to considering the centre of force C removed to an infinite distance, and consequently the radii vectors represented by y infinite, and consequently constant upon the supposition that the velocity in the direction of the curve is uniformly variable, and consequently dz proportional to the equal increments of time, ds may also be taken as constant. Differentiating under these conditions, we have $dz\,.\,ds = d^2 x\,y$, $\frac{dz}{d^2 x} = \frac{y}{ds}$, $\frac{r}{dy} = \frac{y}{ds} = \frac{dz}{d^2 x}$, $r = \frac{dy\,.\,dz}{d^2 x}$. Therefore the equation $f\,dx\,r = v^2 . dz$ becomes $f\,dx\,\frac{dy\,.\,dz}{d^2 x} = v^2 . dz$, $f . dx\,.\,dy = v^2 d^2 x$. Comparing this with the equation $-f\,dy = v\,.\,dv$ already established, and eliminating f, we get $\frac{v^2 . d^2 x}{dx\,.\,dy} = f = -\frac{v\,.\,dv}{dy}$, $v\,.\,d^2 x = -dv\,.\,dx$, $v\,.\,d^2 x + dv\,.\,dx = 0$. Integrating, $v\,.\,dx = C$, which we may put in the form $v\,.\,dx = A\,.\,dz$, dz having been treated as a constant during the investigation.

If we take w to represent the angle at the origin when the co-ordinates are rectangular, we evidently have the following proportion, cos. $w : 1 :: dx : dz$, cos. $w\,.\,dz = dx$. Taking c to represent the initial velocity, $c\,.\,\cos. w\,.\,dz = C$, $v\,.\,dx = c\,.\,\cos. w\,.\,dz$. Comparing this with

$d z = v . d t$, we get $d x = c . \cos. w . d t$; and integrating, $x = c . \cos. w . t$, $\frac{x}{c . \cos. w} = t$. Take $\sin. w = a$, $\cos. w = b$, $\frac{x}{c . b} = t$, $\frac{x^2}{c^2 . b^2} = t^2$.

Produce the ordinate M P, Fig. 3367, to meet the tangent A E in E. E M will evidently represent the descent due to the attraction during the transit of a projectile discharged from the initial point A along the tangential line A E to the point E.

In finding an expression for $M P = y$ in terms of $A P = x$ and known quantities, we might have some difficulty in reducing our formulæ to manageable dimensions; but our familiar spirit g comes to our assistance in his character of $2 . d$, assuming for the time the title of his progenitor, and all the difficulties at once disappear, for according to the conventional rules $2 f s = v^2$; and taking d to represent the descent during the first second, $2 d$ not only represents the generated velocity at the end of the first second, but also upon all other occasions the quantity indicated by f. Substituting $2 d$ for f, $2 . 2 . d . s = v^2$, $4 d s = v^2$. Taking l to represent the height due to the initial velocity c, we get $4 . d . l = c^2$.

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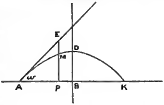

If we take t to represent the time of the transit from A to E and the contemporaneous descent through E M, and referring to the law that "the spaces are as the squares of the times,"

$$1 : t^2 :: d : \mathrm{E M}.$$

Substituting value for t^2, $1 : \frac{x^2}{c^2 . b^2} :: d : \mathrm{E M}$, $\frac{d . x^2}{c^2 . b^2} = \mathrm{E M}$; $b : a :: x : \mathrm{E P}$, $\frac{a x}{b} = \mathrm{E P}$;

$$\{ \mathrm{E P} - \mathrm{E M} \} = \mathrm{M P} = y = \frac{a x}{b} - \frac{d x^2}{c^2 . b^2}.$$

Substituting value for c^2, $y = \frac{a . x}{b} - \frac{x^2}{4 l . b^2}$. It will be evident that when y becomes 0, x will represent the horizontal range, and $\frac{a x}{b} = \frac{x^2}{4 l . b^2}$, $4 a b l = x$.

To find the value of x corresponding to the maximum value of y, or highest point of the trajectory, we must evidently make $d y = 0$, $0 = \frac{a d x}{b} - \frac{2 x d x}{4 l b^2}$, $\frac{a d x}{b} = \frac{2 x . d x}{4 l b^2}$, $2 a . b . l = x$; x is therefore in this case equal to half the range. Substituting this value for x in the equation $y = \frac{a x}{b} - \frac{x^2}{4 l b^2}$, we get $\mathrm{D B} = \frac{2 a^2 b l}{b} - \frac{4 a^2 b^2 l^2}{4 l . b^2} = 2 a^2 l - a^2 l = a^2 l$. This is therefore the value for the ordinate of the highest point of the trajectory. As $\sin. 2 . w = 2 . a . b$, and as $2 l$ represents the initial velocity, and $4 a . b . l = 2 a b . 2 l$ represents the range, it will be evident that the horizontal ranges with the same projectile velocity are as the sines of an angle equal to twice the angle of elevation. The horizontal range will be greatest with a given projectile force when the angle of elevation is 45°; for in this case $a = b$, and their product in the equation $4 a . b . l = x$ will be a maximum. Also all ranges obtained at elevations at equal angles above or below 45° are equal; for the sine in one case becomes the cosine in the other, and *vice versâ*. Oblique ranges (that is, when the object is above or below the level of the battery) may be obtained as follows;—

Take t to represent the tangent and s the secant of the angle of elevation, t' the tangent of the angle of elevation or depression of the object above or below the level of the battery,

$$1 : t' :: x : y = t' . x.$$

Giving this value to y in the equation $y = \frac{a x}{b} - \frac{x^2}{4 l . b^2}$, we get

$$\pm t' x = \frac{a x}{b} - \frac{x^2}{4 l . b^2}, \quad \pm t' = \frac{a}{b} - \frac{x}{4 l . b^2} = \frac{a}{b} - \frac{1}{b^2} \frac{x}{4 l},$$

$$\frac{a}{b} = t, \quad \frac{1}{b^2} = s^2, \quad \pm t' = t - s^2 \frac{x}{4 l}, \quad s^2 \frac{x}{4 l} = t \mp t', \quad x = \{ t \mp t' \} \frac{4 l}{s^2}.$$

This has all come out very smoothly and easily, thanks to the kind assistance of our unalterable friend g: and it would be quite satisfactory, but provokingly enough the shot and shells will not conform to the theory; on the contrary, when they ought to go about twenty miles they collapse, and come to a stop at about a tenth of the distance. This is, to say the least of it, very annoying, after all the trouble we have had in deducing the formulæ. We try to comfort ourselves by saying it is all in the air, and if there was no atmosphere it would be all right. But no one who has ever thrown a stone or shot with a bow and arrow can look at the last figure, or consider the calculation showing that the highest point of the trajectory is over the centre point of the range, without the conviction forcing itself upon him that whatever the curve of the trajectory may be, that is not it.

It is true that we do not as a rule throw stones or practise archery in vacuo; but there is an instinct more reliable than abstract reasoning which tells us that, even leaving out the consideration of the resistance of the air, the true curve should bear a greater analogy to the observable trajectory in nature than the one exhibited to us under the influence of g, who, like all familiar spirits, has the power of making all things easy and pleasant for the present, but can only bring us to infinite trouble and error at the end. This is the theory of the trajectory of projectiles in vacuo, founded upon the laws of gravity, which has been so long received with implicit faith, and only considered inapplicable in practice because the true correction for the resistance of the air has not as yet been discovered.

We shall now consider the theory proposed with reference to the resistance of the air, and in the first place we shall say a few words on the subject of what is commonly called terminal velocity. Upon the supposition that g (the force of gravity, as it is called) remains constant and never changes during the descent of a falling body, although the force of resistance is supposed to augment by successive increments at the end of equal intervals of time, it is assumed that if the descent is continued long enough there must arrive a period at which the aggregate of all the increments of resistance shall equal the force of gravity or g. But it is also supposed that the velocity has gone on constantly increasing during the descent; therefore it is again assumed that at the moment the force of gravity is neutralized by the generated resistance, the greatest velocity attainable by the falling body must have been reached. It is then generally stated that from that moment the body will continue to descend with a uniform velocity equal to the velocity attained. But this is difficult to understand, for the supposition seems to be that at some particular moment of the descent the constantly accumulating force of resistance has reached a degree of intensity which will compensate the impulse of attraction received by the falling body at that moment.

It would therefore seem that there was no further cause for the descent; for, according to the original supposition, in order to receive another impulse of attraction the body should descend during another second of time. But even supposing the possibility of the descent during the succeeding second, the body would then only descend with a constantly augmenting velocity till the impulsive force was again compensated by the resistance. But in order to support the supposition that the velocity is a constantly augmenting velocity, we must also suppose that the successive increments of velocity exceed the corresponding increments of resistance, otherwise it would be either a uniform velocity or else a constantly diminishing velocity. But, on the other hand, unless we suppose that the increments of resistance successively exceed the corresponding increments of velocity, we cannot establish our right to suppose that a period of the descent must arrive when the aggregate of the differences of the increments shall compensate the original balance to the credit of the velocity represented by g. But the whole matter has been rendered so intricate by the anomalous assumption that the velocity increases while the force of which it is the exponent remains constant, that it is impossible to deal with it according to the usual course of argument; and as our present object is simply to exhibit the theory with relation to the correction to be applied for the resistance of the air as it stands at present, we must only assume the generally-received supposition that when the resistance has become equal to the force of gravity (g) the falling body will have attained its greatest velocity, merely remarking, as we pass on, that we have arrived at this conclusion by supposing an absurdity.

Take R to represent the resistance; then, according to the generally-received doctrine, when a falling body has attained its greatest velocity in a resisting medium $R = g$. Referring to the equations $dv = f.dt$; $ds = v.dt$; $\frac{dv}{f} = dt = \frac{ds}{v}$; $f.ds = v.dv$. Integrating upon the supposition that f is constant, $2.s.f = v^2$. f is in this case a constant quantity and is expressed by g. Taking r to represent $2s$ and substituting, we have $rg = v^2$; $g = \frac{v^2}{r}$; $R = g = \frac{v^2}{r}$.

We have thus obtained an expression for the resistance in terms of the velocity and the space through which the body has descended in generating the greatest velocity attainable in the medium through which it moves. But it will be observed that this expression has been obtained by the adoption of the conventional rules, that in the first place f is invariable, and in the second that during the descent the spaces are proportional to the squares of the velocities. It is generally supposed that during the movement of a body through a resisting medium, the resistance acts only on the line of motion, any lateral pressure or action being compensated or neutralized by a corresponding action in the contrary direction. Assuming this supposition to be correct, we shall have only to consider the action of the resisting force on the line of direction of the moving body.

Take the ordinates of the curve A M, Fig. 3368, to represent the successive measures of the motive force, while the corresponding ordinates of another curve A N represent the successive measures of the force of resistance, the abscissa A P expressing the time from the commencement of the motion. It will be evident that the area A M P expresses the sum of all the motive forces during the time represented by the abscissa A P; also that the area A N P expresses the sum of all the forces of resistance from the beginning of the motion during the same time. It follows that the difference represented by the area A M N will express the intensity of the force which generates the actual velocity of a body moving in a resisting medium.

Take y to represent the variable ordinate of the curve A M and y' the ordinate of the curve A N, x the abscissa, a the area enclosed by the curve and ordinates $x.y$, and a' the area enclosed by the curve and ordinates $x'.y'$. Taking the common expression for the differential of an area bounded by a curve related to rectangular co-ordinates,

$$da = y.dx, \quad da' = y'.dx, \quad da - da' = \{y - y'\}.dx.$$

Consequently the differential of the velocity of a body moving through a resisting medium is equal to the product of the difference of the measure of the motive force and the resistance, and the differential of the time elapsed, $dv = \{f - R\}.dt$.

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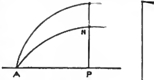

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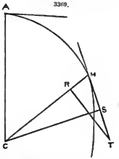

Take C, Fig. 3369, the centre of force; C M = y, the radius vector; C S = s, a perpendicular from the centre upon the tangent at any point M of the curve A M; T M R, the differential triangle, whose sides may be considered as small as we please. The force in the direction C M is to the force in the direction of the tangent as C M : M S. But T M : M R :: C M : M S, $dz : dy :: f : \frac{dy}{dz}f$; therefore $\frac{dy}{dz}.f$ expresses the force in the direction of the tangent. Substituting this value for f in the equation

$$dv = \{f - \mathrm{R}\}.dt,$$

we get $dv = \left\{\frac{dy}{dz}f - \mathrm{R}\right\}.dt$; but $dz = v.dt$; $\frac{dz}{v} = dt$. Substituting this value for dt, $v.dv = dy.f - \mathrm{R}.dz$. We shall now apply this formula to the descent of a falling body. It will be evident that in this case $z = y$, and it has been shown that $\mathrm{R} = \frac{v^2}{r} = f$. We shall also, in order to simplify the calculation, take f equal to unity; g in this case representing f. Therefore $\frac{v^2}{r} = g = 1$; $r = v^2$. Making these substitutions, the expression $v.dv = dy.f - \mathrm{R}.dz$ becomes $v.dv = dy - \frac{v^2}{r}dy = \frac{r - v^2}{r}dy$; $\frac{r.v.dv}{r - v^2} = dy$. Therefore $y = \int\frac{r.v.dv}{r - v^2} = -\frac{1}{2}r\log.(r - v^2) + \mathrm{C}$. But when $y = 0$, $v = 0$; therefore $\mathrm{C} = \frac{1}{2}r\log.r$, and the corrected integral is

$$y = -\frac{1}{2}r\log.(r - v^2) + \frac{1}{2}r\log.r = \frac{1}{2}r\log.\frac{r}{r - v^2};\quad \frac{2y}{r} = \log.\frac{r}{r - v^2}.$$

Take q to represent the number whose log. is $\frac{2y}{r}$,

$$q = \frac{r}{r - v^2};\ q.r - q.v^2 = r;\ r - v^2 = \frac{r}{q};\ r - \frac{r}{q} = v^2;\ (q - 1)\frac{r}{q} = v^2;\ \sqrt{\left\{(q - 1)\frac{r}{q}\right\}} = v.$$

We have thus obtained the value of v in terms of y and r.

Taking the equation $dz = v.dt$, and substituting dy for dz, we get $dy = v.dt$; but $dy = \frac{r.v.dv}{r - v^2}$; $v.dt = dy = \frac{r.v.dv}{r - v^2}$; $dt = \frac{r.dv}{r - v^2}$; $t = \int\frac{r.dv}{r - v^2}$. We have taken g equal to unity, and it has been already shown that under this supposition $r = v^2$. When v is the greatest velocity attainable, take a to represent this velocity, which must evidently be represented by a constant quantity $r = a^2$. Substituting this value, the equation $dt = \frac{r.dv}{r - v^2}$ becomes $dt = \frac{a^2dv}{a^2 - v^2}$;

$$t = a^2\int\frac{dv}{a^2 - v^2} = a^2\frac{1}{2}a\log.\mathrm{C}\frac{a + v}{a - v} = \frac{1}{2}a\log.\mathrm{C}\frac{a + v}{a - v} = \frac{1}{2}a\left\{\log.\mathrm{C} + \log.\frac{a + v}{a - v}\right\}.$$

When $t = 0$, $v = 0$; therefore $\log.\frac{a + v}{a - v} = \log.1 = 0$; therefore $\log.\mathrm{C} = 0$, and the corrected integral is $t = \frac{1}{2}a\log.\frac{a + v}{a - v}$.

We have thus obtained the time of descent of a falling body through a resisting medium in terms of a and v, which as $r = a^2$ amounts to the same as obtaining it in terms of r and v. v has been already obtained in terms of y and r. y is a known quantity, being the distance descended by the falling body. If therefore we can assign a value to r the problem will be solved and the time of descent known. But here again we are led into the region of conjecture and supposition, and find ourselves still under the influence of g. And therefore however sound or ingenious the reasoning may be, if our faith in g is shaken, or if we are not fully satisfied with the suppositions upon which the premises are founded, we must necessarily be sceptical as to the conclusions arrived at. Admitting the assumption that at the moment at which the greatest velocity is attained by a falling body in a resisting medium, the motive force which causes the body to descend must be equal to the force of resistance. Then if we can find expressions for both these forces and equate them together, we may arrive at the value of r, which expresses a uniform velocity, representing the greatest velocity, or, according to the conventional rule, twice the height due to the greatest velocity.

So far we have only considered abstractedly the attractive force which causes a particle of matter to descend; but now, when we are about to deduce a formula adapted to practical application, we must admit the considerations of form and relative density or specific gravity. The fluid with which we have to deal in matters relating to gunnery is the air, and therefore we may consider the specific gravity of the fluid as constant upon all occasions, and represent it by a. The specific gravity of the falling body depends upon the material of which it is composed, but whatever that may be we shall represent it by N.

As we only propose to carry the present investigation so far as may enable us to test the truth of our theories by experiments upon falling bodies, we shall suppose the form of the falling body to be spherical. Take d to represent the diameter of the sphere, then the solid contents will be $\frac{1}{6}\pi d^3$. As we are about to institute a comparison between the motive force and the generated resistance, and as no resistance can be generated till motion takes place, it would be natural to suppose that $\frac{1}{6}\pi d^3 \mathrm{N}$ would be taken to express the initial motive force; but on the contrary, $\frac{1}{6}\pi d^3 (\mathrm{N} - n)$ appears to be generally taken to express the motive force, assuming an initial resistance which seems to be an absurdity.

The expression for the force of resistance is generally arrived at as follows;—The resistance is supposed to vary in proportion to the number of particles which strike a plane moving through the fluid in any given time multiplied into the force with which each particle respectively strikes the plane; but both the number of particles which strike the plane during any given time, as well as the force of each particle respectively, must be proportional to the velocity with which the plane is moving through the fluid; therefore it is concluded that the resistance is proportional to the square of the velocity. It is evidently considered that in arriving at this conclusion it is a sufficiently close approximation for practical purposes to suppose that the action of each particle ceases immediately upon impact with the plane, or, in other words, that the medium through which the plane passes is discontinued. It is supposed by Sir Isaac Newton that in continued media, as air, water, hot oil, quicksilver, &c., a body as it passes through them does not immediately strike against all the particles of the fluid that generate the resistance made to it, but presses only the particles that lie next to it, which press the particles beyond, which press other particles, and so on. It is assumed that the resistance to a plane moving perpendicularly through an infinite fluid at rest is equal to the force of the fluid on the plane at rest, upon the supposition that the fluid moves with the same velocity as the plane was supposed to move with in the first instance, but in a contrary direction. It is also supposed that the force of the fluid in motion is equal to the pressure which causes or generates the motion. If therefore we can find an expression for the pressure of an infinite fluid upon a plane at rest of given dimensions in terms of the velocity of the fluid and known quantities, we can find an expression for the resistance of the fluid at rest to a plane of the same dimensions moving with the same velocity. With reference to this matter there appear to be different theories; but assuming for the present that the pressure of a fluid upon a given plane is equal to the weight or pressure of a column of the fluid, the base of which is equal to the plane and the height equal to the altitude due to the velocity with which the fluid is moving, which according to the conventional rule $= \frac{v^2}{2g}$, $\frac{v^2 . n . a}{2g}$ will equal the weight or pressure of such a column, n representing the specific gravity of the fluid and a the area of the base, and will also express the resistance of the fluid to a body moving through it with the velocity v, the cross-section of the body perpendicular to the line of motion being expressed by a. If the moving body be a cylinder the diameter of the cross-section being represented by d, $a = \frac{\pi . d^2}{4}$.

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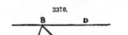

When the cross-section of the moving body is inclined to the direction of motion, let s express the sine of the angle of inclination, A B, Fig. 3370, being the direction of the plane and B D that of the motion. The number of particles or quantity of the fluid which strike the plane will be diminished in the ratio of $1 : s$, also the force of each particle will be diminished in the same ratio. Therefore on these accounts it is supposed the ratio will be diminished in the ratio of $1 : s^2$. But this is upon the supposition that the particles strike the plane perpendicularly, and as they strike obliquely it is considered that the effect will be diminished in the ratio of $1 : s^3$. Therefore upon this supposition $\frac{v^2 . n . s^3 . a}{2g}$ will express the resistance.

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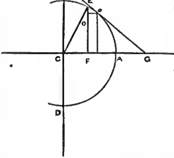


Let B E A D, Fig. 3371, be a section through the axis C A of the solid moving in the direction of that axis; let E G be a tangent to any point in the curve meeting the axis produced in G; let C F and F E represent the ordinates x and y to the point E, E o e the differential triangle; take z to express the arc B E, s the sine of the angle G; $2\pi y$ will equal the circumference described by the point E in revolving about the axis C A; and therefore $2\pi y . dz$ will express the differential of the area opposed to the motion, and $\frac{v^2 . n . s^3}{2g} . 2\pi y . dz = \frac{v^2 . n . \pi s^3}{g} . y . dz$ will express the differential of the resistance. Let the solid be a sphere, and take r to express the radius C A;

$y = \sqrt{(r^2 - x^2)}$; $s = \frac{\mathrm{EF}}{\mathrm{EG}} = \frac{\mathrm{CF}}{\mathrm{CE}} = \frac{x}{r}$; $y.dx = (\mathrm{EF}.\mathrm{E}c) = (\mathrm{CE}.oc) \doteq r.dx$; therefore

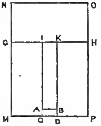
$$\frac{v^2.n.\pi s^3}{g}.y.dx = \frac{v^2 n \pi}{g}\frac{x^3}{r^3} r\,dx = \frac{v^2 n \pi}{g r^2} x^3.dx; \quad \int \frac{v^2 n \pi}{g r^2} x^3.dx = \frac{v^2 n \pi}{4 g r^2} x^4;$$

when $x = r$, $\frac{v^2.n.\pi}{4 g r^2} x^4 = \frac{v^2.n.\pi.r^2}{4g}$. Taking d to represent the diameter of the sphere, $\frac{v^2 n \pi d^2}{16 g}$ will express the resistance. Equating this expression with $\frac{1}{6}\pi d^3 (\mathrm{N} - n)$, the expression for the motive force, we have $\frac{v^2.n.\pi d^2}{16 g} = \frac{1}{6}\pi d^3 (\mathrm{N} - n)$; $v^2 = 2g\frac{4}{3}d\frac{\mathrm{N}-n}{n}$; $\frac{v^2}{2g} = \frac{4}{3}d\frac{\mathrm{N}-n}{n}$. But as v has been taken to express the greatest velocity, $\frac{v^2}{2g}$ will express the height due to such velocity; but $r =$ twice the height due to the velocity v, therefore $r = \frac{8}{3}.d.\frac{\mathrm{N}-n}{n}$, or $r = \frac{8}{3}d\frac{\mathrm{N}}{n}$, upon the supposition that at the commencement of the motion the resistance $= 0$.

Having thus obtained a value for r we can obtain a value for the time of descent of a spherical body of any given dimensions and specific gravity through any given space represented by y.

It has been assumed in the preceding investigation that the pressure of a fluid upon a given plane is equal to the weight or pressure of a column of the fluid, the base of which is equal to the plane and the height equal to the altitude due to the velocity of the fluid. This is generally proved as follows:—

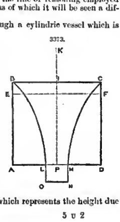
3372.



Take M N O P, Fig. 3372, to represent a vertical section of a cylindrical vessel filled with a fluid up to the level G H, at which height it is supposed to be always retained; M P the diameter of the base, and C D the diameter of a circular orifice in the base, which is supposed to be very small compared with M P; C I K D a section of a column of the fluid standing directly above the orifice, and C A B D a section of a plate of the fluid immediately contiguous to the orifice. Take v to denote the velocity with which the plate C A B D would descend in vacuo through the space B D, subject only to the influence of gravity. Take V to denote the velocity with which the plate C A B D is discharged from the orifice when subjected to the pressure of the entire volume of the fluid, which a reference to any elementary work will show may, according to theoretical reasoning, be represented by the column C I K D. The velocities are as the moving forces, and the times in which they act directly and inversely as the quantity of matter moved; but it will be evident upon the supposition that the fluid is homogeneous that the moving forces will be as the heights B D and K D. The times in which they act are inversely as the velocities, the space being given, namely B D, and the quantities of matter moved equal, the quantity of matter in both cases being represented by the plate of fluid A C D B; therefore $v : \mathrm{V} :: \frac{\mathrm{BD}}{v} : \frac{\mathrm{KD}}{\mathrm{V}}$; $v^2 : \mathrm{V}^2 :: \mathrm{BD} : \mathrm{KD}$; $v : \mathrm{V} :: \sqrt{\mathrm{BD}} : \sqrt{\mathrm{KD}}$. But B D is the height due to the velocity v, therefore K D is the height due to the velocity V, and K D is the height of the fluid. It will be observed that in this case V represents the velocity at the orifice, not the mean velocity of the descent of the fluid. The pressure on the orifice is equal to a column of the fluid of which the base is equal to the area of the orifice and the altitude equal to the height of the fluid. Therefore, admitting the usual suppositions, and also that the result in the case just investigated may be taken to represent the resistance in an unconfined fluid, the problem is solved.

The following may be taken as representing to a certain extent the line of reasoning employed in Prop. 36, Lib. II., of Newton's Principia in this matter, by means of which it will be seen a different result is arrived at.

3373.



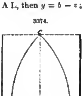
Take A B C D, Fig. 3373, to represent the vertical section through a cylindric vessel which is supposed to remain constantly full of water. To illustrate this, Sir Isaac Newton supposes a block of ice on the top of the vessel, the lower surface of the ice being in contact with the upper surface of the water, so that as the water descends through an orifice in the bottom of the vessel, of which L M represents the diameter, the ice shall dissolve and constantly supply the deficit. If we take E F to represent the line of surface at any variable distance B E, which line of surface had been originally at B C, it will be evident that the quantity of water run out at the orifice during the descent from B C to E F will be represented by E B C F. Take U to represent the quantity of water contained in the vessel, m the area of the circular surface at B C, and m' the area of the circular orifice of which L M is the diameter; then as the velocities of equal quantities of water through different openings during the same time are inversely as the areas of the openings taking V to represent the velocity at the orifice and V' the velocity at the surface B C, we have $\mathrm{V} : \mathrm{V}' :: m : m'$. Take x equal A B the height of the fluid, and $a + x$ the height due to the velocity at the orifice, $\mathrm{V}^2 : \mathrm{V}'^2 :: m^2 : m'^2 :: a + x : \frac{m'^2}{m^2}(a + x)$, which represents the height due to the velocity at B C; therefore, while $a + x$ represents the height due to the velocity at the orifice, $\frac{m'^2}{m^2}(a + x)$ will represent the height due to the velocity at the surface. Differentiating both these expressions, we have $d\,x$ and $\frac{m'^2}{m^2}\,d\,x$. Assuming the differential of the height due to the mean velocity of the fluid as equal to the difference of the above differentials, we have $d\,x - \frac{m'^2}{m^2}\,d\,x$ to represent the differential of the height due to the mean velocity of the descending fluid; therefore $d.\mathrm{U} = \left\{d\,x - \frac{m'^2}{m^2}\,d\,x\right\} m = m\,d\,x - \frac{m'^2\,d\,x}{m}$, also $\mathrm{U} = m.x$. If v represents the mean velocity with which the water descends, the momentum of pressure upon the base may be expressed by $\mathrm{U}.v$ according to conventional rule. $m\,x$ evidently expresses the quantity of water contained in the vessel, which multiplied with the distance of the centre of gravity of the mass of water from the plane of the bottom of the vessel, will express the momentum also. But in this case the distance of the centre of gravity from the bottom of the vessel upon which the pressure is applied $= \frac{1}{2}x$; therefore taking M to represent the momentum, $\mathrm{U}.v = \mathrm{M} = \frac{1}{2}m\,x^2$. Differentiating, $v.d\,\mathrm{U} + \mathrm{U}\,d\,v = m.x.d\,x$. Substituting the values for $d\,\mathrm{U}$ and U already found, we have $v.m.d\,x - v\frac{m'^2}{m}\,d\,x + m\,x\,d\,v = m\,x.d\,x$; dividing by m, $v.d\,x - v\frac{m'^2}{m^2}\,d\,x + x.d\,v = x.d\,x$. Take $\left(1 - \frac{m'^2}{m^2}\right) = r$, $r.v.d\,x + x\,d\,v = x\,d\,x$. Multiplying both sides of this equation by x^{r-1}, $r.v.x^{r-1}.d\,x + x^r.d\,v = x^r.d\,x$; integrating, we obtain $v\,x^r = \frac{x^{r+1}}{1+r}$; dividing by x^r, $v = \frac{x}{1+r}$. We assumed $1 - \frac{m'^2}{m^2} = r$; therefore

$$2 - \frac{m'^2}{m^2} = \frac{2\,m^2 - m'^2}{m^2} = 1 + r \therefore\; v = \frac{x}{1+r} = \frac{m^2\,x}{2\,m^2 - m'^2}.$$

Take K I to represent the height due to the velocity at the surface, and K P the height due to the velocity at the orifice, K I : K P :: $\mathrm{V}'^2 : \mathrm{V}^2$, $\mathrm{V}' : \mathrm{V}$ :: $\mathrm{P\,L}^2 : \mathrm{I\,B}^2$, $\mathrm{V}'^2 : \mathrm{V}^2$ :: $\mathrm{P\,L}^4 : \mathrm{I\,B}^4$, K I : K P :: $\mathrm{P\,L}^4 : \mathrm{I\,B}^4$; this determines the curve B L, and the cataract B L M C is formed by the revolution of this curve about the axis K P. It is supposed that the contents of this cataract expresses the quantity of water which presses upon the orifice in the same manner as if the rest was congealed into ice; therefore the portion of the water contained in the solid described by the same curve B L round the axis B A expresses the quantity which presses upon the ring described by A L in the rotation.

Let $a\,b$, Fig. 3374, represent the diameter of this ring, and $a\,c\,b$ a section of the solid described by the revolution. Take a to express K I, x = I P, b = B I, y = P L, z = A L, then $y = b - z$; therefore by the property of the curve, $a : a + x :: y^4 : b^4$; $\frac{a\,b^4}{y^4} = a + x$; $\frac{a\,b^4}{y^4} - a = x$. Substituting value for y^4, $\frac{a.b^4}{(b-z)^4} - a = x$. Differentiating, $\frac{4\,a\,b^4\,d\,z}{(b-z)^5} = d\,x$. But the differential of the solid described by the area A B L about the axis A B = x is equal to the cylinder whose base is the circle described by the ordinate A L = z and altitude equal to $d\,x$. This solid is therefore proportional to $z^2.d\,x$, while $z^2.x$ expresses the cylinder of the same base and altitude, $z^2\,d\,x = \frac{4\,a\,b^4\,z^2\,d\,z}{(b-z)^5} = \frac{a\,b^2}{3}\,\frac{12\,b^2.z^2\,d\,z}{(b-z)^5}$. Therefore the solid $a\,c\,b$ will be proportional to $\frac{a\,b^2}{3}\int\frac{12\,b^2\,z^2\,d\,z}{(b-z)^5}$. Take $12\,b^2 = \mathrm{M}$,

3374.



$$\mathrm{M}.\int z^2\frac{d\,z}{(b-z)^5} = z^2\,\frac{1}{4\,(b-z)^4} - \int\frac{1}{2}\,z\,\frac{d\,z}{(b-z)^4};\quad \int\frac{1}{2}\,z\,\frac{d\,z}{(b-z)^4} = \frac{1}{2}\,z\,\frac{1}{3\,(b-z)^3} - \int\frac{1}{6}\,\frac{d\,z}{(b-z)^3};$$

$$\int\frac{1}{6}\,\frac{d\,z}{(b-z)^3} = \frac{1}{6}\,\frac{1}{2\,(b-z)^2}. \text{ Therefore } \int z^2\frac{d\,z}{(b-z)^5} = \frac{z^2}{4\,(b-z)^4} - \frac{z}{6\,(b-z)^3} + \frac{1}{12\,(b-z)^2} + \mathrm{C}.$$

When $z = 0$, $0 = \frac{1}{12\,b^2} + \mathrm{C}$, $\mathrm{C} = -\frac{1}{12\,b^2}$; therefore the corrected integral is

$$\frac{z^2}{4\,(b-z)\,4} - \frac{z}{6\,(b-z)^3} + \frac{1}{12\,(b-z)^2} - \frac{1}{12\,b^2} = \frac{3\,z^2 - 2\,z\,(b-z) + (b-z)^2}{12\,(b-z)^4} - \frac{1}{12\,b^2}$$

$$= \frac{3\,b^2\,z^2 - 2\,b^2\,z\,(b-z) + b^2\,(b-z)^2 - (b-z)^4}{12\,b^2\,(b-z)^4}$$

$$= \frac{3\,b^2\,z^2 - 2\,b^3\,z + 2\,b^2\,z^2 + b^4 - 2\,b^3\,z + b^2\,z^2 - b^4 + 4\,b^3\,z - 6\,b^2\,z^2 + 4\,b\,z^3 - z^4}{12\,b^2\,(b-z)^4} = \frac{4\,b\,z^3 - z^4}{12\,b^2\,(b-z)^4};$$

$$\mathrm{M}\int z^2 \frac{dz}{(b-z)^5} = \frac{4bz^3 - z^4}{(b-z)^4}.$$

Therefore the solid acb is proportional to $\frac{ab^3}{3}\,\frac{4bz^3 - z^4}{(b-z)^4}$. Substituting value for x in $z^2 x$, we have $\frac{az^2 b^4}{(b-z)^4} - az^2 = az^2\left\{\frac{b^4}{(b-z)^4} - 1\right\}$; therefore the solid is to the cylinder as

$$\frac{ab^3}{3}\,\frac{4bz^3-z^4}{(b-z)^4} : az^2\left\{\frac{b^4}{(b-z)^4}-1\right\} = \frac{b^3}{3}\,\frac{4bz^3-z^4}{(b-z^4)} : \frac{z^2\{b^4-(b-z)^4\}}{(b-z)^4} = \frac{b^2}{3}(4bz^3-z^4) : z^2\{b^4-(b-z)^4\}.$$

But $z^2\{b^4 - (b-z)^4\} = 4b^3z^3 - 6b^2z^4 + 4bz^5 - z^6$; therefore the proportion becomes

$$\frac{4b^3z^3 - b^2z^4}{3} : \{4b^3z^3 - 6b^2z^4 + 4bz^5 - z^6\};$$

or dividing by z^3, $\left\{\frac{4}{3}b^3 - \frac{1}{3}b^2 z\right\} : \{4b^3 - 6b^2 z + 4bz^2 - z^3\}$. If we suppose z to become infinitely small, or in other words suppose the diameter at the orifice to approach without limit to an equality with the diameter at the surface, all the terms involving z may be neglected, and the proportion will become $\frac{4}{3}b^3 : 4b^3$, or $\frac{1}{3} : 1$; and also m', which has been taken to represent the area of the orifice, may be taken equal to m, the area at the surface, and $v = \frac{m^2 x}{2m^2 - m'^2}$ becomes $v = x$. Therefore x equals twice the height due to the velocity v.

If we suppose the water to be at rest, and the small circle of which ab represents the diameter to ascend with the velocity equal to v with which the water was supposed to descend, it will be evident that the same expression which represented the pressure when the fluid was in motion and the circle at rest will represent the resistance when the circle is in motion and the fluid at rest; but the solid representing the pressure in the first case is to the cylinder whose base is the small circle and altitude x, as $\frac{1}{3} : 1$, and consequently the resistance will bear the same proportion. It follows that in order to meet with a resistance equal to the pressure of the cylinder the small circle must move with a velocity equal $3.v$; but the heights due to any given velocities are as the squares of the velocities, therefore twice the height due to the velocity $3.v$ will equal $9.x$; but this is upon the supposition that the cylinder is of the same specific gravity as the fluid.

If we suppose the small circle which forms the base of the cylinder to remain constant, and also the velocity, then in order to express the pressure which denotes the resistance we must reduce the altitude x of the cylinder in proportion to the increase in the specific gravity. Take N to represent the specific gravity of the cylinder, and n the specific gravity of the fluid; then if we suppose the velocity to be the greatest velocity attainable in the medium in which the body is moving, and r to represent twice the height due to such velocity when the specific gravity of the moving body is represented by N and that of the fluid by n, we have $r : 9x :: \mathrm{N} : n$, the sphere is $\frac{2}{3}$ of the cylinder. If therefore we suppose the specific gravity of the sphere to be N, and the specific gravity of the circumscribing cylinder to be $\frac{2}{3}$ N, the pressure which is the exponent of the resistance will be the same if we substitute the cylinder for the sphere; therefore when the form of the moving body is spherical, the proportion becomes, taking d to represent the diameter of the sphere and consequently the height of the circumscribing cylinder, and substituting it for x, $r : 9d :: \frac{2}{3}\mathrm{N} : n$; $r = \frac{6.\mathrm{N}.d}{n}$.

It will be observed that in arriving at this conclusion the resistance to solid bodies moving through a fluid is supposed to be the same, when the cross-sections of the solids at right angles to the line of motion are equal without reference to the form of the solid.

In Lemma IV., Lib. II., of the Principia, we find the following;—If a cylinder move forward uniformly in the direction of its length, the resistance made thereto is not at all changed by augmenting its length or diminishing that length, and is therefore the same with the resistance of a circle described with the same diameter, and moving forward with the same velocity in the direction of a right line perpendicular to its plane; for the sides are not at all opposed to the motion, and a cylinder becomes a circle when its length is diminished *ad infinitum*. The force of the last part of the reasoning is not immediately apparent, for if the cylinder is not diminished *ad infinitum* it does not become a circle.

In the report of a lecture on the flight of projectiles, delivered at the R. U. S. Institution in 1865 by General Anstruther, we find the following statement made by the Editor of the present work; —"It has been found by experiment on railways that the resistance of the atmosphere to the motion of a train depends chiefly upon the length of the train and not upon the frontage of the carriages; the resistance resembles more that of friction than the moving of a long parallelopiped of the fluid in which the body moves."

It is generally supposed that when the velocity of a body moving through a resisting medium exceeds a certain limit the resistance becomes increased, in consequence of a vacuum being formed in rear of the moving body, leaving the body to sustain the whole force of the resistance of the particles of the fluid opposed to the motion without any support from the particles moving in, in rear, upon the track of the moving body. This is supposed to take place when the velocity of the moving body exceeds the velocity with which the particles of the air subjected to the pressure of a column equal in height to the height of the atmosphere will rush into the orifice supposed to be left by the advance of the moving body. Sound moves at the rate of 1142 ft. in a second, and as sound is propagated by the elastic force of the air, therefore the elastic force of the air is such as to produce an equivalent velocity; this is therefore sometimes taken to mark the limit from which the vacuum is formed.

Much has been written on these subjects by Newton, Bernoulli, D'Alambert, Bossut, Bunt, and many other authors; and a good abridgment of all that can be said on the subject, assuming the established laws of gravity, will be found in the Treatise on Artillery for the practical class of the R. M. Academy, published by authority in 1866. But instead of entering further into detail in these matters, we should propose in the first place that we should test by actual experiment the accuracy of our present theory founded upon the laws of gravity generally received. If the experiment should prove the theory to be fallacious, the next step we should propose would be to endeavour to ascertain by experiment where the fallacy exists—whether in an erroneous estimate of the resistance of the air, or of the force of gravity, or both. We have facilities of experiment now which were not formerly attainable in the same degree. These may be furnished by the improvements in the construction and mode of working balloons, by electricity, photography, telegraphy, accuracy in measuring time, as well as in graduating and constructing optical instruments; and add to all these a calculus which will enable us to solve problems which were formerly beyond our reach—the calculus to which we allude is Dual Arithmetic, a new Art.

The first experiment we should propose is as follows;—That on a calm, favourable day an ascent should be made in a balloon carrying a spherical body of known density, as homogeneous as it is possible to make it; that an observer should be stationed at any convenient point for taking the elevation of the balloon at any given time; that the spherical body should be attached to the car of the balloon, so as to be detached suddenly, at a signal, by means of the suspension of an electric current—the weight of the shot, indicated by a spring balance, should be token at the instant it is detached from the car; that the signal should be given from the point of observation at the moment that the elevation is taken by means of a theodolite or other suitable instrument; that the height of the balloon from which the body drops should be estimated by a single observation, the distance from the point of observation to the point where the spherical body drops being taken as radius, and the tangent of the observed angle to such radius, added to the height of the observer's eye, being taken as the height of the balloon. We have given a formula by means of which the time of descent may be calculated according to the theory now extant; the diameter and density of the falling body, the height descended as well as the moment of detachment being known; the time of descent being accurately noted and compared with the time by calculation will show the amount of discrepancy which may exist between them. If the discrepancy is great, we must conclude that our theory is fallacious; and, on the other hand, if the times nearly agree, we may conclude that our theoretical formulæ are sufficiently close approximations to the truth for practical purposes, and we may go further into detail to improve it. If we find a sensible discrepancy, which is most likely to be the case, we must then have recourse to further experiment, in order to discover where the fallacy exists.

We have assumed the descent of the spherical figure to be vertical; that is, that the falling body descends upon a vertical straight line in the direction of the plumb-line. It appears to us that the error incurred in consequence of this assumption will be less than the error arising from two observations which may not be simultaneous. If the single observation should be taken exactly at the moment that the spherical body is detached, and the time correctly noted, the only source of error will be the irregular motion during the descent of the spherical body, and the experiment will be much simplified, as it will be only necessary to measure the distance from the point of observation to the point where the spherical body reaches the ground. Even upon the supposition that the exact vertical height of the balloon was ascertained by a double observation, the error arising from irregularity of the motion in the descent would remain.

We shall now give a short extract from a small pamphlet lately published, entitled Theory of Gunnery, offered to the Institution of Civil Engineers by Gen. Anstruther;—

"When a ball has been projected obliquely upwards it is acted upon by two forces—the resistance of the atmosphere and gravity; the former of these two can only act in reducing the magnitude of the ascent, the latter of the two deflects the ascent vertically, so as to bring the ball to the ground at the expiration of a certain time of flight, at a distance from the gun called the range.

"If the true angle of departure is given to us as the elevation, and the horizontal space passed over as the range, we can determine the trajectory to an inch.

"We multiply the given range in feet by the tangent of the elevation; the product is the measure of the vertical descent, the fall by gravity in the time of flight."

This offers a useful suggestion for further experiment in order to test the validity of our present theory of gravity. The angle made by the axis of the gun, or the tangent to the curve of trajectory at the initial point and the direction of the object, is called the angle of elevation. The angle of departure required by the General is the true angle of elevation with the horizon, or complement of the zenith distance, which latter is the angle made by the vertical passing through the point of projection and the direction of the piece. This angle being known, the General considers that the vertical deflection during the time of flight will be equal to the tangent of the given angle to a radius equal to the measured range. If this be the case, it evidently suggests another means of ascertaining the time of descent through a given distance under the influence of gravity and the resistance of the air; for the height descended will be known by calculation, and the time by observation (being the time of flight).

The results of these two experiments being compared together, and with the results by calculation according to the existing theory, might lead to some useful conclusions. The resistance of the air is evidently a retardative force, with the law of which we are at present unacquainted. It is generally supposed that it acts only on the line of motion of the projectile, but as the initial impulse becomes weaker in consequence of the augmenting force of resistance, the ratio of the impulsive force to the force of gravity is constantly changed, and the deflecting power of the force of gravity becomes comparatively stronger as the projectile proceeds; from this cause alone the force of gravity also varies by some law, as the moving body approaches nearer and nearer to the centre of force. These variations would render the determination of the curve rather an intricate matter, even if we were acquainted with the laws of variation, which at present we are not. But if a tolerably close approximation to the laws of variation could be arrived at by experiment, the means of calculation for the formation of reliable tables could be soon found.

Admitting the statement that a body impelled by a given force in a given direction will proceed with a *uniform velocity* in that direction *ad infinitum*, unless influenced by some counteracting force; admitting also that the force of gravity acts on parallel vertical lines, and the force of resistance of the air only on the line of trajectory of the projectile, it would follow that the time of flight should be a very close approximation to the time of descent through a distance equal to the vertical deflection, calculated according to General Anstruther's theory; and the matter might be tested by dropping shot from a balloon at different heights, and also observing the time of flight corresponding to different ranges, interpolating in both cases, and comparing the results.

We shall now pass on to experiments with a view to ascertain as nearly as possible by a practical test the respective laws of variation, of gravity, and the resistance of the air. We shall here extract some remarks, by the Editor of the present work, on this subject, to be found in the report of General Anstruther's lecture, delivered at the R. U. S. Institution in 1866; also the calculation of certain formulæ, which we shall here modify so far as to put them in a more explanatory form than that in which they appear in the report;—

"To find whether the resistance of the air or any other fluid medium is proportional to the square of the velocity (V) or not, and also to find whether the value usually given to (g) the force of gravity near the surface of the earth is under or over estimated, generally g is put $= 31\frac{1}{3}$, $32\frac{1}{6}$, 32, &c. Let v^2 multiplied by some constant coefficient express the retarding force, and to simplify the investigation put this coefficient under the form $n^2 g$; then the motive force will be expressed by $g - g n^2 v^2$. Taking the equation $dv = f.dt$, and substituting $g(1 - n^2 v^2)$ for f, we have $dv = g(1 - n^2 v^2)dt$; $\dfrac{dv}{1 - n^2 v^2} = g.dt$; $\dfrac{1}{g n^2} \dfrac{dv}{\frac{1}{n^2} - v^2} = dt$; $\dfrac{1}{g n^2} \displaystyle\int \dfrac{dv}{\frac{1}{n^2} - v^2} = t$. Assume $\dfrac{1}{n} = a$, the expression becomes $\dfrac{a^2}{g} \displaystyle\int \dfrac{dv}{a^2 - v^2} = t$, which reduces it to a well-known form, and we have $\dfrac{a}{2g}\left\{\log.\dfrac{a+v}{a-v} + \log.\text{C}\right\} = t$. When $v = 0$, $t = 0$; therefore $\dfrac{a}{2g}\log.\text{C} = 0$, and the corrected integral is $\dfrac{a}{2g}\log.\dfrac{a+v}{a-v} = t$; $\log.\dfrac{a+v}{a-v} = \dfrac{2gt}{a}$.

Take $2gt = m$, and ϵ to represent the base of the hyp. logs.,

$$\frac{a+v}{a-v} = \epsilon^{\frac{m}{a}}; \quad a + v = a.\epsilon^{\frac{m}{a}} - v\epsilon^{\frac{m}{a}}; \quad v\{\epsilon^{\frac{m}{a}} + 1\} = a\{\epsilon^{\frac{m}{a}} - 1\}; \quad v = a\frac{\epsilon^{\frac{m}{a}} - 1}{\epsilon^{\frac{m}{a}} + 1}.$$

Substituting value for a, $v = \dfrac{1}{n}\dfrac{\epsilon^{m.n} - 1}{\epsilon^{m.n} + 1}$.

Taking the equation $v.dv = f.ds$; substituting as before $g(1 - n^2 v^2)$ for f, we have $v.dv = g(1 - n^2 v^2)ds$; $\dfrac{v.dv}{1 - n^2 v^2} = g.ds$; $\dfrac{v.dv}{g(1 - n^2 v^2)} = ds$; which may be put under the form $-\dfrac{1}{2n^2 g}\dfrac{-2n^2 v.dv}{(1 - n^2 v^2)} = ds$; therefore $-\dfrac{1}{2n^2 g}\log.\dfrac{1}{1 - n^2 v^2} + \log.\text{C} = s$. When $v = 0$, $s = 0$; therefore $\log.\text{C} = \log.1 = 0$, and $-\dfrac{1}{2n^2 g}\log.\dfrac{1}{1 - n^2 v^2} = s$; but

$$v = \frac{1}{n}\frac{\epsilon^{m.n} - 1}{\epsilon^{mn} + 1}; \qquad v^2 = \frac{1}{n^2}\frac{(\epsilon^{2mn} - 1)^2}{(\epsilon^{2mn} + 1)^2};$$

therefore $$n^2 v^2 = \frac{(\epsilon^{2mn} - 1)^2}{(\epsilon^{2mn} + 1)^2}; \quad 1 - n^2 v^2 = \frac{(\epsilon^{2mn} + 1)^2 - (\epsilon^{2mn} - 1)^2}{(\epsilon^{2mn} + 1)^2};$$

$$(\epsilon^{2mn} + 1) + (\epsilon^{2mn} - 1) = 2\epsilon^{2mn}; \quad (\epsilon^{2mn} + 1) - (\epsilon^{2mn} - 1) = 2.$$

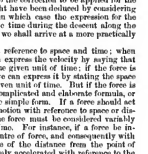
Therefore $1 - n^2 v^2 = \dfrac{4\epsilon^{2mn}}{(\epsilon^{2mn} + 1)^2}$; $\quad \dfrac{1}{1 - n^2 v^2} = \dfrac{(\epsilon^{2mn} + 1)^2}{4\epsilon^{2mn}} = \left\{\dfrac{\epsilon^{2mn} + 1}{2\epsilon^{mn}}\right\}^2 = \left\{\dfrac{1}{2}\left(\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}}\right)\right\}^2$. Substituting this value for $\dfrac{1}{1 - n^2 v^2}$ in the expression $-\dfrac{1}{2n^2 g}\log.\dfrac{1}{1 - n^2 v^2} = s$, we have $\dfrac{1}{n^2 g}\cdot\dfrac{1}{2}\log.\left\{\dfrac{1}{2}\left(\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}}\right)\right\}^2 = s$; or $\dfrac{1}{n^2 g}\log.\dfrac{1}{2}\left(\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}}\right) = s$; $\log.\dfrac{1}{2}\left(\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}}\right) = s n^2 g$. Therefore $\dfrac{1}{2}\left(\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}}\right) = \epsilon^{sn^2 g}$; $\epsilon^{mn} + \dfrac{1}{\epsilon^{mn}} = 2\epsilon^{sn^2 g}$; we assumed $m = 2gt$. Substituting this value, we have $\epsilon^{2gtn} + \dfrac{1}{\epsilon^{2gtn}} = 2\epsilon^{sn^2 g}$, which is under the form $y + \dfrac{1}{y} =$ a function of s, g, and may be solved by dual arithmetic." See DAMMING.

Then if we drop a spherical body, as homogeneous as it can be made, from a balloon upon a calm day and can mark exactly the time of descent, s and t in the equation become known quantities, ϵ being the base of the hyperbolic system of logarithms, dual log. of $\epsilon = 100000000, = 10^8$; there evidently remain only n and g unknown quantities. Repeating the experiment and ascertaining two new values for s and t, we obtain a second equation, in which n and g are the only unknown quantities. Therefore, having two equations and only two unknown quantities, we can ascertain the values of n and g. Taking the equation $v = \frac{1}{n}\,\frac{\epsilon^{mn} - 1}{\epsilon^{mn} + 1}$, then since g and t are known quantities m becomes a known quantity, and consequently v. The corresponding resistance also becomes known, having been originally assumed as $g\,n^2.\,v^2$; we can therefore compare the velocities with the resistance in the two experiments, and thus ascertain the ratio which subsists between them.

We commenced this article by assuming as a fact that bodies under the influence of the force of gravity and uninfluenced by any sensibly counteracting force move in elliptical orbits round the centre of force. This being all that we may be said to know of the action of the law of gravity by actual observation, the rest being more or less founded upon ingenious suppositions of clever men, which suppositions have become so familiar to us, and such an imposing structure of mathematical reasoning has been raised upon them, that we forget the original instability of the foundation. We should therefore propose that the ratio of the times of descent with reference to the space descended through found by experiment should be compared with the ratio of the times calculated with reference to the law of gravity found by observation, namely, that the force or velocity is inversely proportional to the square of the distance from the centre of force. And then if the differences of the times found by experiment and calculation should bear a constant ratio to each other, we may assume that this difference represents a close approximation to the correction to be applied for the resistance of the atmosphere. A formula for this purpose might have been deduced by considering the minor axis in the ellipse to be indefinitely diminished, in which case the expression for the time in the elliptical orbit would become an expression for the time during the descent along the line of the transverse axis. But in the present case we think we shall arrive at a more practically useful result, as follows;—

We can only represent a force or its exponent velocity by a reference to space and time; when the force is singly impulsive and the velocity uniform we can express the velocity by saying that it is such as to cause a motion of so many feet or yards in one given unit of time; if the force is constant and the velocity uniformly accelerated or retarded, we can express it by stating the space generated or due to the acceleration or retardation during a given unit of time. But if the force is variably accelerated or retarded we can only express it by a complicated and elaborate formula, or else approximate to it as closely as may be desirable in a more simple form. If a force should act according to any law of uniformly accelerated or retardative motion with reference to space or distance from the centre of force, it will be evident that the same force must be considered variably accelerated or retarded when referred to equal intervals of time. For instance, if a force be inversely proportional to the square of the distance from the centre of force, and consequently with relation to a falling body directly proportional to the square of the distance from the point of departure, it will be evident that the motion, although uniformly accelerated with reference to the space or distance descended, will be variably accelerated when referred to equal portions of the time of descent, that is, the space which expresses the distance due to the acceleration during any one interval of time will not be equal to the space which expresses the distance due to the acceleration during any other equal interval of time.

3375.



Take the abscisses A P, A P', A P'', &c., Fig. 3375, to represent the times, and the corresponding ordinates P M, P' M', P'' M'', &c., to represent the spaces described. We shall suppose the ordinates P M, P' M', P'' M'', &c., to be indefinitely near to each other; also the distances P P', P' P'', &c., to be equal to each other, or in other words $d\,t$; which they represent, to be constant. Draw M K parallel to the axis of the abscisses and produce the chord M M' to X. Let T R be a tangent to the curve at the point M'; then K M = Q X = $d\,s$ will represent the space due to the acceleration during the interval of time P P'. If the motion was to become uniform at the point M' the line of motion would be represented by the tangent M' R. It will be evident therefore that M'' R will represent the space due to the acceleration during the interval of time P' P''; T M' = M' R; T M and M'' R are parallel; therefore T M = M'' R upon the supposition that the curvature is the same throughout. In the triangles T M M', R M' X, T M' = M' R, and the angles are equal; therefore

$$\mathrm{T\,M = R\,X,\ \ M''\,R = T\,M = R\,X,\ \ X\,M'' = 2\,M''\,R};\ \ \mathrm{K\,M} = d\,s,$$
$$\mathrm{K\,M' - Q\,M'' = Q\,X - Q\,M''} = -\,\mathrm{X\,M''} = d^2\,s;\ \ -\,2\,\mathrm{M''\,R} = d^2\,s.$$

Here the motion has been considered with reference to the point of departure of a body falling towards the centre of force, and consequently the velocity is accelerative and the curve convex towards the axis of the abscisses. But if we consider it with reference to the point at which the falling body reaches the ground, estimating from that point towards the point of departure, the velocity must be taken as retardative; the curve will be concave towards the axis of the abscisses, and the expression becomes $2\,\mathrm{M''\,R} = d^2\,s$. The equation $2\,s = f\,d\,t^2$ was arrived at upon the supposition that f was constant. Although this supposition appears to be inadmissible with reference to the entire time of descent of a falling body, and only productive of error and confusion, still the application may be considered admissible without sensible error with reference to the movement through the first of the indefinitely short equal intervals of time into which the line of descent is supposed to be divided. In this case s in the formula expresses the space due to the acceleration during the short interval of time $d\,t$, s will therefore be represented by M″ R,

$$f\,d\,t^2 = 2\,\mathrm{M}''\,\mathrm{R} = d^2 s\,; \quad f = \frac{d^2 s}{d\,t^2}.$$

The intensity of the force of attraction may be supposed to become infinitely great at the centre of force, or whether infinite or not it is constant and may be represented by m; but we can always suppose the representation of the intensity of the force at some constant distance from the centre nearer to it than any distance which we shall have to consider, and therefore in our calculations the quantity expressing this force may be considered constant; let it be represented by m. The fact of its being a constant quantity whatever its actual value may be will be sufficient to enable us to institute a comparison of ratios with reference to other forces at a greater distance from the centre. The distance of the point of departure of a falling body from the centre of force is known, being equal to the radius of the earth added to the line of descent, and may therefore be also represented by a constant quantity. Let this latter be represented by a. Then when the intensity of the attractive force is inversely proportional to the square of the distance from the centre of force, taking s to represent the line of descent, we have $\frac{m}{(a-s)^2} = f$; therefore $\frac{d^2 s}{d\,t^2} = f = \frac{m}{(a-s)^2}$; $\frac{d\,s}{d\,t} = v$. Upon the supposition that $d\,t$ is constant,

$$\frac{d\,s}{d\,t}\,.\,d\left(\frac{d\,s}{d\,t}\right) = v\,.\,d\,v\,; \quad \frac{d^2 s}{d\,t^2}\,.\,d\,s = v\,.\,d\,v = \frac{m\,d\,s}{(a-s)^2}.$$

Integrating, $v^2 = \frac{2\,m}{a-s} + \mathrm{C}$. Upon the usual supposition that when $v = 0$, $s = 0$, $\mathrm{C} = -\frac{2\,m}{a}$; and the corrected integral is

$$v^2 = \frac{2\,m}{a-s} - \frac{2\,m}{a} = \frac{2\,m\,a - 2\,m\,a + 2\,m\,s}{a\,(a-s)} = \frac{2\,.\,m\,.\,s}{a\,(a-s)}\,; \quad v = \sqrt{\frac{2\,m}{a}}\cdot\sqrt{\frac{s}{(a-s)}}\,;$$

therefore when $s = a$, v is infinite. In $v = \sqrt{\frac{2\,m}{a}}\cdot\sqrt{\frac{s}{a-s}}$, substitute $\frac{d\,s}{d\,t}$ for v;

$$\frac{d\,s}{d\,t} = \sqrt{\frac{2\,m}{a}}\ \sqrt{\frac{s}{a-s}}.$$

Taking the reciprocals,

$$\frac{d\,t}{d\,s} = \sqrt{\frac{a}{2\,m}}\cdot\sqrt{\frac{a-s}{s}}\,; \quad d\,t = \sqrt{\frac{a}{2\,m}}\,\sqrt{\frac{a-s}{s}}\,d\,s\,; \quad t = \sqrt{\frac{a}{2\,m}}\int\sqrt{\frac{a-s}{s}}\,d\,s.$$

Multiply both terms of the fraction by $\sqrt{(a-s)}$, we get

$$\frac{a-s}{\sqrt{(a\,s-s^2)}}\,d\,s = \frac{\frac{1}{2}\,a-s}{\sqrt{(a\,s-s^2)}}\,d\,s + \tfrac{1}{2}\,a\,\frac{d\,s}{(a\,s-s^2)}\,;$$

$$t = \sqrt{\frac{a}{2\,m}}\left\{\int\frac{\frac{1}{2}\,a-s}{\sqrt{(a\,s-s^2)}}\,d\,s + \frac{a}{2}\int\frac{d\,s}{(a\,s-s^2)}\right\}; \quad \int\frac{\frac{1}{2}\,a-s}{\sqrt{(a\,s-s^2)}}\,d\,s = \sqrt{(a\,s-s^2)}.$$

To find the integral of $\frac{d\,s}{\sqrt{(a\,s-s^2)}}$, take $s = \frac{1}{2}\,a - z$; $d\,s = -\,d\,z$;

$$a\,s - s^2 = \tfrac{1}{2}\,a^2 - a\,z - (\tfrac{1}{4}\,a^2 - a\,z + z^2) = \tfrac{1}{2}\,a^2 - a\,z - \tfrac{1}{4}\,a^2 + a\,z - z^2 = \tfrac{1}{4}\,a^2 - z^2 = \frac{a^2 - 4\,z^2}{4}\,;$$

$$\sqrt{(a\,s-s^2)} = \frac{\sqrt{(a^2-4\,z^2)}}{2}\,; \quad \frac{d\,s}{\sqrt{(a\,s-s^2)}} = \frac{-\,2\,d\,z}{\sqrt{(a^2-4z^2)}}\,; \quad \int\frac{-\,2\,d\,z}{\sqrt{(a^2-4\,z^2)}} = \cos.^{-1}\frac{2\,z}{a}.$$

We have taken $s = \frac{1}{2}\,a - z$, therefore

$$z = \tfrac{1}{2}\,a - s\,; \quad 2\,z = a - 2\,s\,; \quad \frac{2\,z}{a} = \frac{a-2\,s}{a}\,; \quad \int\frac{d\,s}{\sqrt{(a\,s-s^2)}} = \cos.^{-1}\frac{a-2\,s}{a}\,;$$

$$t = \sqrt{\frac{a}{2\,m}}\left\{(a\,s-s^2) + \tfrac{1}{2}\,a\cos.^{-1}\frac{a-2\,s}{a}\right\}.$$

When $t = 0$, $s = 0$; therefore the above is the correct integral.

If $s = a$, $\sqrt{\frac{a}{2\,m}}(a\,s-s^2) = 0$, and $\frac{a-2\,s}{a} = -\,1 = \cos.\ 180^\circ$; therefore in this case

$$\cos.^{-1}\frac{a-2\,s}{a} = \pi\,; \quad t = \sqrt{\frac{a}{2\,m}}\cdot\frac{1}{2}\,a\,\pi = \frac{1}{\sqrt{8\,m}}\,a^{\frac{3}{2}}\,;$$

therefore the times of the descent of falling bodies from different heights would be as the square roots of the cubes of the lines of descent, upon the supposition that the force of attraction is inversely proportional to the square of the distance, and that there is no resistance; for the radius of the earth being constant the lines of descent will be as the distance from the point of departure of the falling body to the centre of force represented by a.

A careful comparison of the results of these experiments might lead to the discovery of the two great secrets, the law of gravity near the surface of the earth, and the correction to be applied for the resistance of the air. We believe that it would be also possible to obtain the trace of the trajectory of a shell if not of a round shot at short range and slow velocity by means of photography. The instrument should be placed at such an angle as to bring a sufficient portion of the range within the field of the lens to admit of our determining the general law of the curve. We should then have an oblique view of the range, the abscissæ being foreshortened, while the ordinates would be in their due proportion; but the angle at which the instrument had been placed with reference to the line of direction being known, the abscissæ could be calculated in their true proportions, and thus the law of the curve might be obtained.

There are three forces to which a projectile during its trajectory is subjected—the attractive force of gravity, the resistance of the air, and the initial propelling force. We have spoken of the first two in this article, and the third and last will be found treated of under the heads GUNPOWDER; ORDNANCE.

We have little doubt that a series of experiments carefully conducted, utilizing the improved means and appliances now at our disposal, would lead to a much closer approximation of calculated formulæ to practical results than has been as yet attained, enabling us to generalize, interpolate, and form corrected and at the same time practically useful tables. But to the prosecution of such experiments an insuperable objection appears to arise; they require appliances and means not usually at the disposal of private individuals, and the same stimulus to enterprise and risk of loss which exists in all matters relating to improvements in mechanical action when profit follows immediately upon successful results, does not exist in this case. Probably some would be inclined, in the interests of science alone, to carry out experiments of this kind if they were in possession of the means; but an assortment of large guns, balloons, voltaic batteries, and photographic apparatus, does not, as a general rule, form a portion of the properties of a gentleman of the period. Those therefore who are specially interested in facilitating the destruction of their fellow-creatures must only wait patiently till the matter is taken up by some of our foreign neighbours, and then, if they should be successful in discovering the true laws of gravity and resistance, we may be able to purchase the secret. But in the meantime we may console ourselves with the reflection that there is no absolute necessity for further discovery or improvement, for we find it stated by authority with reference to the effect of the resistance of the atmosphere to the motion of a projectile, that sufficient is known to guide the practical artillerist, and that it is only as a scientific question that any further prosecution of the subject is of interest, and this more on account of the difficulty of solution than for its practical importance. This fact being established, there remains little inducement to proceed further with an inquiry into the laws of gravity and the resistance of the air, for it is a difficult and intricate subject to deal with; and if no practically useful results are to be expected, and if it is merely an abstract inquiry into the laws of nature which is aimed at, the world is going much too fast for anything of that sort now. But even if we have arrived at the summit of perfection in the matter of artillery practice, it seems to be generally admitted, since long ranges have become the fashion, that some mode of ascertaining the distance in action more accurate than the unassisted estimate by the human eye is desirable. We shall therefore say a few words on this subject presently, p. 1772.

Fig. 3376 is of an instrument employed by General Anstruther to illustrate his system of gunnery.

1. Two bars, A B and B C, are joined by a hinge at B; they are to represent the ascent and descent of a projectile fired at any elevation with any velocity. A third bar A′ C′ represents the horizontal range; it is graduated by being divided into equal spaces of 100 yds. each, from A′ towards C′, 100, 200, 300, 400, &c., &c., yards, for the greatest range attainable. This bar A′ C′ has two collars, one fixed at A′, representing the place of the gun, the other movable to represent the point where the ball falls. Each of these collars has a ring through which the bars A B and B C will pass, and a milled-headed screw fixes them in their desired place. The horizontal bar is mounted on trestles to admit of the unemployed portion of A B and B C passing under the horizontal range.

2. Then A′ B C′ will always form a right-angled triangle, and we graduate A B and B C by dividing them so as to show the fall by gravity in the successive seconds, 1, 2, 3, 4, &c., &c., as far as we wish to do it, or can calculate the fall; then on B C we write the spaces described in the successive seconds, and on B A the velocity acquired; the two bars will therefore be graduated thus;—

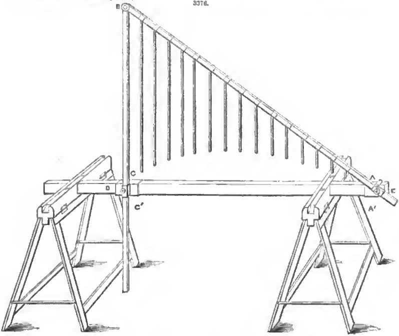
Time	1	2	3	4	5	6	7	8	9	10, &c.
B C	16·2	64·4	144	254·4	395	565·2	764·4	992	1247·4	1530, &c.
A B	31·8	64·1	95·1	125·6	155·5	184·8	213·5	241·6	269·1	296, &c.

3. These three bars thus graduated enable us to show the right-angled triangle formed by the simultaneous ascent and descent of any ball fired obliquely upwards; and we proceed to show how the trajectory is drawn.

4. For this purpose a set of metal rods, tinned or plated iron wire, are prepared, one for each second of time, as shown in our paragraph 2, where we show the space described by a falling body.

These are hung on the points of graduation of the oblique ascent, in an inverted order of succession, that is to say, the shortest rod lowest down; then a line drawn through the lower extremities of all these rods is the trajectory.

3376.



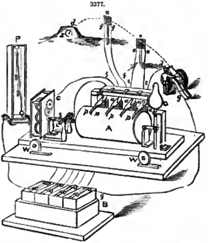
Example.—To draw the trajectory of a ball fired at an elevation of 11° 58′ 56″·25, with initial velocity 736 ft. a second, we set the bar A B in the ring of the collar at A, and clamp it to shew velocity 736 ft., and we bend A B down to the desired angle, clamping its vertical bar B C at a distance of 5877·5 ft. from A′, and proceed to hang the metal rods for 1, 2, 3, 4, 5, 6, 7, 8, and 9 seconds on the oblique ascent; the last of these meets the range exactly, and we see the trajectory marked by ten given points; our Table showing the fall by gravity will enable us to give this curve for the tenth parts of seconds if required.

This instrument was offered to the service in 1864, when the model of which the above is a drawing was lodged in the United Service Institution.

Fig. 3377 is of an Electro-Chronoscope, invented by Major-General Anstruther, C.B. The object of the electro-chronoscope is to measure exactly the time of flight of a projectile between two given points. Various modes of taking the time of flight have been in use for years. The simplest is a sort of clock, which is divided into 600 parts, and which is traversed by a hand once a minute, and which may be set going and stopped by touching a lever, and from which a second hand may be detached in its course. It indicates to tenths of seconds; but, as the accuracy of this instrument depends upon the manipulation of the observer, it is subject to considerable error. The self-registering principle is therefore the only one which will give reliable results.

General Anstruther had an apparatus designed by Mr. Helmes, which was entrusted to Messrs. Elliott for execution. The principle was in the main the same as represented in the woodcut. A cylinder, covered with paper soaked in a solution of ferrocyanide of potassium, had to revolve driven by a weight. Small iron wheels attached to slight springs had to trace, by decomposition, blue lines on the paper, on the principle of Bain's electric printing telegraph, as long as an electric current passes; but when put into practice it was found that, if we may call it *so*, a sort of ink was formed which continued to mark after the current was broken, and consequently the object aimed at, extreme accuracy, was lost. In conjunction with Mr. Bashley Britten, Messrs. Elliott altered the plan. Instead of making use of chemical decomposition by an electric current, they substituted metallic paper for the cylinder A, and a clockwork C for the weight. At *a a a a* of sketch are four electro-magnets made of the same material, in exactly the same manner, a matter of some importance, as we shall presently see. The keepers are attached to springs which carry metallic points *p p p p*. When the electric current makes the iron magnetic, the keeper is attracted, and the metallic point presses gently on the paper; one of the electro-magnets is in connection with an accurately-timed seconds pendulum, which at every beat makes connection for a fraction of a second, or, in other words, makes the magnet attract the keeper every second, and dots on the paper cylinder. Thus we have a second registered independently of the velocity with which the cylinder rotates. If the rotation is quicker, the two dots will be farther apart, and *vice versâ*. The three other electro-magnets are in electric connection with three targets, one of which is distant about 1 ft. from the muzzle of the gun, the second and third at 100 or 200 yds., or at any other required distance. The first target consists of a simple copper wire, which is broken by the ball leaving the gun. The targets Nos. 2 and 3 consist of frames of common deal wood 6 ft. square, across which a copper wire passes backwards and forwards close enough to allow no ball to pass through without breaking it. These frames can be raised to such a height as the angle of elevation at which the gun is fired renders necessary. The cylinder A has a screw S cut on its axis, which serves as a means of propelling it while the metallic points draw, so that the lines do not fall upon each other, but run spirally round the cylinder with the pitch of the screw. For that purpose the cylinder with clockwork is fixed to a carriage which runs on the wheels while the lever L and the metallic points at *p p p p* remain stationary. At the farther end is a governor to ensure equal velocity of rotation. This governor should be a friction governor made of discs of felt, like the governor of House's printing telegraph. A governor of this kind would render this instrument complete.

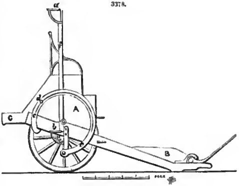
3377.



The apparatus is used in the following manner;—A galvanic battery is connected with each of the four electro-magnets; one takes into its circuit the pendulum, the second the target at the muzzle of the gun, the third the target at 100 yards distance, the fourth the target at 200 yards; the pendulum is then set going, and dots on the cylinder, which is, however, not yet in motion. The clockwork is now set going, and the three points draw lines. After one or two revolutions the command to fire is given, when the ball, in leaving the gun, breaks the wire of No. 1 target, and point No. 1 ceases to draw. When the second target is struck, point No. 2 ceases to draw; and when the third target is struck, point No. 3 ceases to draw. The clockwork is now stopped. To ascertain the time represented by these lines, the paper is taken off; where point No. 1 has ceased to draw is the starting point or zero; the length of the second and third lines will give seconds and fractions of seconds, when compared with the distance of the two dots made by the pendulum, for which purpose a scale may be used, or an ingenious contrivance of Mr. Holmes's, a compass to one leg of which a screw is attached with 100 turns, a nut turns in the second leg and subdivides one turn of the screw into 100 parts. By moving the trammels either way the points of the compass can be made to take in the two dots which represent the second, and each turn of the screw will give the 100th part of the second, be the distance great or small. A second cylinder is provided, which may be prepared with metallic paper beforehand so as to save time. Various objections may be raised to this apparatus, to some of which we will briefly allude. Electricians will point out that after the current is broken residue magnetism in the soft iron will retard the release of the keeper. We have provided against this error, firstly, by making the electro-magnets exactly alike, as mentioned before, so that we have the same retardation in the release of the three different keepers, and this error will thus be neutralized; secondly, by not bringing the keeper into actual contact with the iron, but interposing a thin brass pin. A second objection might be that the different length of the wires might have different or unequal effects on the magnets; if this should be the case, resistance coils might be enclosed in the currents to make them all alike. A third source of error, and perhaps the most inconvenient one, is, that when the three points draw, there is more friction than when they are successively released; but as the amount of friction can be ascertained, it can be allowed for.

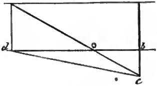
We have examined many *Telemeters* and *Range-finders*, each of which, with the exception of the one, Fig. 3378, had defects that rendered it of little or no use in action. The instrument, Fig. 3378, consists of a vertical bar *f*, of metal, about 9 ft. (3 yds.) long, mounted upon a carriage in the form of a gun-carriage, as shown in the figure. Two quadrants *a b* are attached, one at each extremity of the metal bar, so that the centres of rotation of the movable limbs of the quadrants shall be exactly 9 ft. apart, and that the zeros of the instruments and the centres of rotation of the movable limbs shall be correctly in the same line. With the aid of a telescope, movable in the quadrants *a b*, mounted with level and micrometer screw, tangents of angles of elevation or depression can be almost instantly found with a high degree of accuracy. The axletree-boxes are raised so as to form small platforms for the observer at the higher level to place his feet upon, and there is a small rail in front, as shown in the figure, for him to rest his hand upon while observing. The lower extremity of the bar is about 3 ft. from the level of the ground, so that an observation can be taken with what we term the quadrant on the lower level in a kneeling position. The bar and boxes rotate upon an axle placed a little above the lower quadrant, so as to admit of the bar being depressed when the observation is completed, the quadrant *a* falling into a small case fitted to receive it at B, and the quadrant at *b* fitting into a similar case near the point C. A handle and crank *d*, moving upon a circular bar *c c*, is attached, and there is a counterweight at C in order to facilitate the elevation and depression of the bar.

3378.



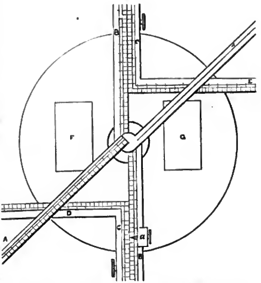
Use of the Instrument.—In Fig. 3378 the near wheel is removed as well as the axletree-box on the near side. The tangents of angles of depression of a distant point are taken at both levels and read off by the observers, the distance or range being thus calculated or worked out by means of a calculating instrument, as hereafter described, by a third man appointed for that purpose. The calculating instrument is shown in Fig. 3380, a small platform at B being constructed to work the calculating instrument upon.

3379.



If the radius or range of the quadrants *a b* equal 10 in., divided into tenths, and if the micrometer screw divides $\frac{1}{10}$ of an inch into 100 equal parts, then the 10-in. radius = 10000; such equal parts and the difference of the tangents of the two observed angles at *a* and *b* may be found to be $\frac{1}{10000}$ of an inch = ·0001 = 20″·6 nearly. If greater accuracy be required, and a $\frac{1}{10}$ vernier be applied to the micrometer screw, then the radius is taken = 100000 equal parts, and the tangents are measured to $\frac{1}{100000}$ of an inch = ·00001 = tangent of 2″ nearly.

3380.



The principle upon which the instrument, Fig. 3378, works may be shown as follows:—

Let $\theta = \angle$ of observation at the higher level, *a s c*, Fig. 3379; $\theta' = \angle$ observed angle at the lower elevation, *b d c*; $r = sd$, the length of the vertical bar *a b*, Fig. 3378; $R = db$, the horizontal range; *c* the position of the enemy's battery; then

$$sd : bc :: do : ob;$$

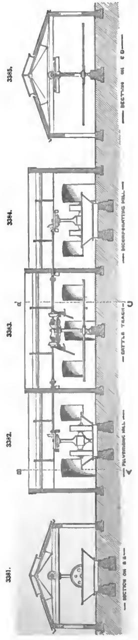
$$\therefore sd : (sd+bc) :: do : (do+ob).$$

Since $sd = ab$, we have $(\tan.\,\theta - \tan.\,\theta') : \tan.\,\theta :: r \operatorname{cotan.}\theta : R$;

$$r\frac{\tan.\,\theta \operatorname{cotan.}\,\theta}{\tan.\,\theta - \tan.\,\theta'} = R;$$

$$\therefore r\frac{1}{\tan.\,\theta - \tan.\,\theta'} = R.$$

In this demonstration we put the radius = 1; but suppose the radius = 10000 equal parts, which we take as a whole number, then the horizontal range $R = \frac{r \times 10000}{\tan.\,\theta - \tan.\,\theta'}$. Now if tan. θ measures 2 in. 4–10ths and 69 from the micrometer circle, and



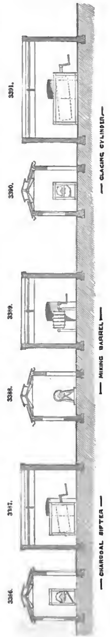
3381. — SECTION ON A B —

3382. — PULVERISING MILL —

3383. — BATTLE TRACK —

3384. — INCORPORATING MILL —

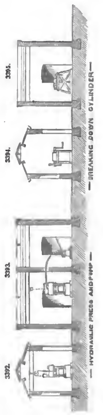
3385. — SECTION ON C D —



3386. 3387. — CHARCOAL SIFTER —

3388. 3389. — MIXING BARREL —

3390. 3391. — GLAZING CYLINDER —



3392. 3393. — HYDRAULIC PRESS AND PUMP —

3394. 3395. — BREAKING DOWN CYLINDER —

tan. $\theta' = 2$ in. 4-10ths and 48 from the micrometer circle, then tan. $\theta -$ tan. $\theta' = 2469 - 2448 = 21$, and as $r = 3$ yds., we have $R = \frac{30000}{21} = 1429$ yds., the horizontal range very nearly. The calculating instrument before alluded to, Fig. 3380, forms a vast variety of similar triangles, which instantly give a fourth proportion to tan. $\theta -$ tan. θ', r, and 10. The divisions on the sides B, B; D, E, are all equal and not in logarithmic order. The calculating instrument consists of a circular disc F G attached to a vertical limb B B, upon which two horizontal limbs D and E, with clamping screws, slide vertically; upon the lower branch of the limb B B a small marker a, with clamping screw, slides vertically; a diagonal bar A A revolves upon the centre point of the circular disc; two small tables of tangents F and G are engraved upon the disc. The instrument is worked as follows;—While the first observation is being taken on the higher level, move the horizontal limb E to 10 on the upper branch of the vertical limb B B and clamp it; upon the observation at the higher level being taken and read off, move the marker a on the lower branch of the vertical limb B B to the number answering to tan. θ; upon the observation at the lower level being read off, move the horizontal limb D till the number answering to tan. θ' coincides with the number on the vertical limb B B indicated by the marker a, and clamp it. Bring the revolving diagonal bar to the number on the horizontal limb D corresponding to r. The upper arm of the diagonal bar will indicate a number which multiplied mentally by 10, 100, or 1000, according to the graduation of the instrument, will give the horizontal range. Nolan makes $r = \frac{b}{\sin. (\beta + \gamma)}$, and tries to obtain results by divisions put in logarithmic order on circular rings. Nolan's reasoning looks extremely scientific, but in practice all such performances are extremely ridiculous. See Anemometer. Angular Motion. Artillery. Damming. Dynamometer. Gunpowder. Gyration. Ordnance. Oscillation. Percussion.

GUNPOWDER. Fr., *Poudre à canon;* Ger., *Schiesspulver;* Ital., *Polvere da cannone;* Span., *Pólvora.*

The mechanical part of the manufacture of gunpowder is essentially the same in principle, and differs only to an immaterial extent in detail, whether in the various gunpowder mills in Great Britain or in those of the Continent.

The annexed engravings show a complete set of gunpowder machinery, manufactured for the Japanese Government by J. and H. Gwynne, of the Hammersmith Iron Works, London. In consequence of the objection to steam-power as increasing the danger of explosions, and the absence of sufficient water, it was found necessary to drive the mills by cattle-power.

Fig. 3381 shows a side view of the pulverizing mill, Fig. 3382 a front view of the same; Fig. 3383 shows the arrangement of the cattle track; Fig. 3384 the front view of the incorporating mill; Fig. 3385 is a side elevation of the cattle track; Figs. 3386, 3387, different views of the charcoal sifter; Figs. 3388, 3389, different views of the mixing barrel; Figs. 3390, 3391, different views of the glazing cylinder; Figs. 3392, 3393, different views of the hydraulic press and pump; Figs. 3394, 3395, different views of the breaking-down cylinder.

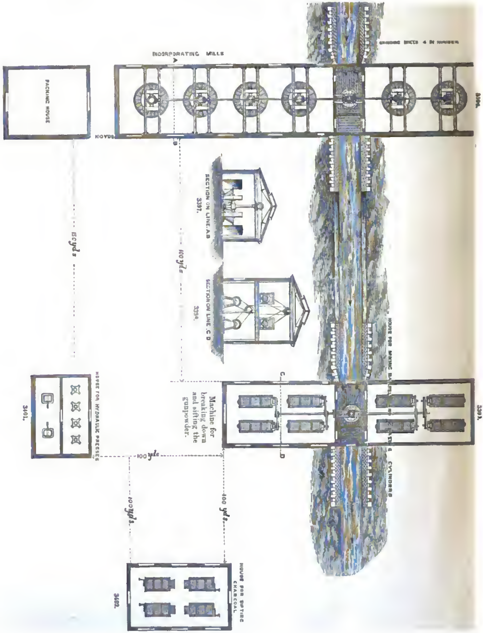
Figs. 3396 to 3402 exhibit another arrangement of gunpowder machinery, made for the Italian Government by J. and H. Gwynne. In this case water-power was available, and was thus made use of to drive the machinery by means of two turbine water-wheels, as shown. Figs. 3396, 3397, show a plan and section of the house containing the mills; Figs. 3398, 3399, show a section and plan of the house containing mixing barrels, glazing cylinders, machines for breaking down and sifting the gunpowder; Fig. 3400 is the packing house; Fig. 3401 the house containing hydraulic presses; Fig. 3402 the house for sifting charcoal. The houses are all made of as slight material as possible, so that in case of an explosion the powder has as little surface to act upon as possible, and are placed at such a distance apart so that the one may not be endangered by the other. The machinery in Figs. 3396 to 3402 is exactly similar to that in Figs. 3381 to 3395, but on a somewhat larger scale.

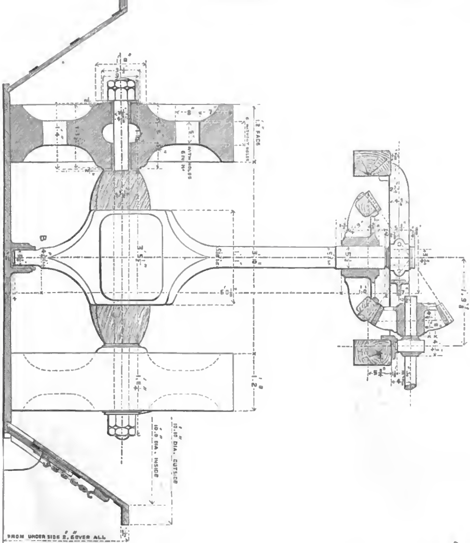
Figs. 3403 to 3406 give sectional views of the pulverizing and incorporating mill to a larger scale. This machine is made upon the latest and most improved construction, the rolls and pan being made of cast iron, which after many experiments has been found to be the most suitable material for the purpose; the upright and cross spindles are both made of wrought iron, working in gun-metal bearings at each end; the outside frame of the pan is made of wood, and the whole is worked from the main driving shaft by a pair of bevel-wheels, as shown in Fig. 3403. These details are necessary in order to explain the full working of the machinery.

The materials having been pulverized in the mill, Fig. 3381, are apportioned out, the following being the proportions used at the Government mills, Waltham Abbey, and also by other makers generally;—

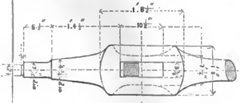
	lbs.	oz.	drachms.
Saltpetre	31	8	0
Charcoal	6	4	13
Sulphur	4	3	3
	42	0	0

This quantity of the ingredients, termed a charge, is placed in the mixing apparatus, Figs. 3388, 3389, which consists of a wooden cylinder, traversed in its centre by an octagonal shaft provided with several fan-like arms. Both the shaft and cylinder are kept in motion, but in different directions. This latter arrangement so facilitates the commingling that the homogeneous powder is ready for removal and further manipulation in from five to ten minutes, when it is transferred to bags which are pressed, and the mouths of which are firmly secured, in order to prevent the disunion or separation of the ingredients in the order of their density during the transport to the incorporating mill. It is evident if the charges were too lightly packed the ingredients would be liable to be separated, the saltpetre finding its way to the bottom, while the

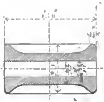

INCORPORATING MILLS
A
B
100YDS
GRINDING MILLS 4 IN NUMBER
3396.
3400.
PACKING HOUSE
150yds
SECTION ON LINE A B
3397.
SECTION ON LINE C D
3398.
100yds
HOUSE FOR MIXING ... CYLINDERS
3399.
C
D
Machine for breaking down and sifting the gunpowder.
HOUSE FOR HYDRAULIC PRESSES
3401.
100yds
100yds
100yds
HOUSE FOR SIFTING CHARCOAL
3402.



3403.



3405.



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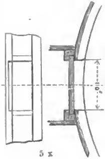


3404.

5 x

sulphur and charcoal would form layers above, the latter, from its light pulverulent state, escaping in the form of dust between the fibres of the cloth of which the bag is formed.

The next process is the incorporation. The mixture is spread out upon the bed of the mill, Fig. 3384, and distilled water is added to ensure the intimate cohesion of the particles, and the whole is again submitted to the action of the mill to ensure the uniform pressure and bruising of the ingredients; but in this case the motion is less rapid than during the grinding of the ingredients. A great degree of caution must be exercised to prevent the intervention of any hard or silicious matters. The requisite amount of moisture must be maintained during the operation, and for this purpose water is slowly added at suitable intervals till the incorporation is complete, which is generally the case at the expiration of from three to four hours.

The compound has now the properties of gunpowder; it indurates in a very short period, forming hard cakes, termed mill-cake. When it has lost some of its moisture, but before it becomes completely dry, it is passed between the breaking-down cylinder, Figs. 3394, 3395, and is then submitted, between copper plates placed in strong boxes, to hydraulic pressure of about 150 tons to the sq. ft., in the press house, Figs. 3392, 3393.

The powder has now to be granulated, and for this purpose it is placed in the breaking cylinder, Figs. 3394, 3395, and afterwards sifted by hand to the various degrees of fineness. The finest powder is then placed in the glazing cylinder, Figs. 3390, 3391, in a slightly moist state, and revolved very slowly, so that the grains become polished by attrition. The gunpowder is finally dried, which is now generally done by means of steam heat, and sometimes by a current of air, previously heated in another chamber from 130° to 150°, passing over the powder placed on canvas shelves.

On Fig. 3403 the footstep B will have to be covered with wood, in order to prevent the grains of powder being exploded from getting between the shaft and brass.

By mixing intimately saltpetre with charcoal or with sulphur, we obtain substances which, when subjected to a high temperature, deflagrate and suddenly develop a large volume of gas. When the combustion takes place in a contracted space considerable pressure is exerted on the surrounding walls of this space, and if one of these be movable, it may be projected with more or less force.

If, for example, 1 equivalent of nitre KO,NO_5 is mixed with 1 equivalent of carbon, there are produced, by detonation, 1 equivalent of carbonate of potassa, 1 equivalent of nitrogen, and 3 equivalents of oxygen; $KO,NO_5+C=KO,CO_2+N+3O$; 2 volumes of nitrogen and 3 of oxygen will therefore be disengaged.

We may calculate by approximation the volume of gas developed by one volume of the detonating mixture. 1 equivalent of nitrate of potassa weighing 1264·3, and 1 equivalent of carbon weighing 25·0, the weight of the mixture will therefore be 1339·3. Assuming that this pulverized mixture occupies the same volume as an equal weight of water, we can admit that a weight 1339·3 grammes of the mixture will occupy a volume of 1·339 lit. Now, this weight of the mixture develops 1 equivalent = 175 of nitrogen, and 3 equivalents = 300 of oxygen.

1 lit. of nitrogen, at 32°, under a pressure of 0·760 m., weighs 1·257 gramme.
1 „ oxygen „ „ „ „ 1·429 „

The volume occupied by the nitrogen at 32°, and under a pressure of 0·760 m., will be given by the proportion $1·257 : 1·000 :: 175 : x$, whence $x = 139·2$ lit. The volume occupied by the disengaged oxygen under the same circumstances will be deduced from the proportion

$$1·429 : 1·000 :: 300 : y, \text{ whence } y = 209·9 \text{ lit.}$$

Thus a volume of detonating mixture represented by 1·339 lit. yields 349·1 lit. of gas at 32°, and under a pressure of 0·760 m.—a volume 253 times greater than that of the explosive substance. The volume of gas, at the moment of development, is really much larger than we have just found, being strongly dilated by the high temperature produced by the combustion; and we may safely admit that the expansion is at least three times greater than that given by calculation, when the gas was supposed to have a temperature of 32°.

If 1 equivalent of nitrate of potassa is mixed with 2 equivalents of carbon, then 1 equivalent of carbonate of potassa, 1 equivalent of nitrogen, 1 of carbonic acid, and 1 of oxygen are formed; $KO,NO_5+2C=KO,CO_2+N+CO_2+O$. The equivalent of carbonic acid being represented by 2 volumes, it will be seen that 5 volumes of gas are still disengaged; that is, that the expansion is the same as in the preceding case. The projectile force may, however, be greater if a high temperature be developed during the combustion.

Lastly, if 4 equivalents of carbon are added to 1 equivalent of nitre, then 1 equivalent of nitrogen and 3 equivalents of oxide of carbon are disengaged; $KO,NO_5+4C=KO,CO_2+N+3CO$. 1 volume of oxide of carbon containing only a ½ volume of oxygen, it is evident that 6 volumes of oxide of carbon will be developed; the gaseous volume will therefore be equal to 8. Thus there will be a greater production of gas than in the two preceding cases. The projectile force might, however, be less, if the heat developed be not so great. Moreover, in the mixture we have just supposed, a great portion of the carbon does not ignite.

Mixtures of nitre and sulphur also produce, by detonation, considerable volumes of gas. Thus a mixture of 1 equivalent of nitre and 1 equivalent of sulphur yields 1 equivalent of sulphate of potassa, 1 equivalent of nitrogen, and 2 equivalents of oxygen; $KO,NO_5+S=KO,SO_3+N+2O$; 4 volumes of gas will therefore be formed.

With 1 equivalent of nitre and 2 equivalents of sulphur we have

$$KO,NO_5+2S=KO,SO_3+N+SO_2;$$

that is, again 4 volumes of gas; for the equivalent of sulphurous acid is represented by 2 volumes.

A mixture of 1 equivalent of nitre with 4 equivalents of sulphur gives

$$KO,NO_5+4S=KS+N+3SO_2;$$

2 volumes of nitrogen and 6 volumes of sulphurous acid will therefore be disengaged; in all, 8 volumes of gas. In fact, however, the gaseous volume is less considerable, owing to the incomplete combustion of the sulphur.

Mixtures of nitre and carbon generally produce a greater volume of gas than mixtures of nitre and sulphur: but the latter have the advantage of being more combustible.

Experiments have proved that the mixtures possessing the greatest projectile force consist of nitre, carbon, and sulphur. A mixture of

1 equivalent of nitre	1264	66·0
1 equivalent of sulphur	200	10·5
6 equivalents of carbon	450	23·5
	1914	100·0

gives $KO,NO_5+S+6C=KS+N+6CO$; that is, 14 volumes of gas. But in reality the gaseous volume is less considerable, because a large portion of the carbon escapes combustion, and the temperature does not rise very high.

The following mixture possesses a greater projectile force;—

1 equivalent of nitre	1264	74·8
1 equivalent of sulphur	200	11·9
3 equivalents of carbon	225	13·3
	1689	100·0

We then have $KO,NO_5+S+3C=KS+N+3CO_2$, with the disengagement of 8 volumes of gas.

We may calculate by approximation the volume of gas produced by a volume (1) of this mixture. Let us again admit that the mixture occupies the same volume as an equal weight of water. We shall say that 1689 grammes of the mixture, or a volume of 1·689 lit., disengages 175 grammes of nitrogen = 139·2 lit., and 825 grammes of carbonic acid = 417·3 lit.; total gaseous volume = 556·5 lit. A volume (1) of the detonating mixture will therefore produce 329 times its volume of gas at 32° and under a pressure of 0·760 m. of mercury.

The numerous experiments made in all countries to discover empirically the best composition for powder show that it should be as approximate as possible to that just now theoretically developed.

In France three different compositions are in use.

For war powder—

Saltpetre	75·0
Sulphur	12·5
Charcoal	12·5
	100·0

For sporting powder—

Saltpetre	76·9
Sulphur	9·6
Charcoal	13·5
	100·0

For blasting powder—

Saltpetre	62·0
Sulphur	20·0
Charcoal	18·0
	100·0

Prussian war powder shows the following composition—

Saltpetre	75·0
Sulphur	11·5
Charcoal	13·5
	100·0

English and Austrian war powder—

Saltpetre	75·0
Sulphur	10·0
Charcoal	15·0
	100·0

Swedish war powder—

Saltpetre	75·0
Sulphur	16·0
Charcoal	9·0
	100·0

Chinese powder—

Saltpetre	75·7
Sulphur	14·4
Charcoal	9·9
	100·0

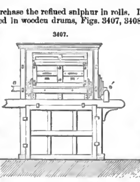
French blasting powder is the only one which differs remarkably from the theoretical composition just indicated; this is because a great projectile force is not required, and the Government, which imposes a considerable tax on sporting powder, endeavours to manufacture a blasting powder such that it cannot be substituted for the former. This powder has, indeed, less strength, and fouls the gun very rapidly.

Powder should satisfy several conditions, which vary according to the weapon in which it is to be used. When it is very explosive, and the explosion of the charge is instantaneous, the reaction on the walls of the weapon is sudden and violent, frequently causing the weapon to burst; the powder is then said to be too *explosive*. If the powder is not sufficiently explosive, the projectile is thrown from the weapon before all the charge is burned; a portion of the latter, therefore, is uselessly inserted and wasted. The powder most suitable for any given weapon is that which, burning perfectly whilst the projectile passes through the chamber of the piece, communicates to it, gradually, and not instantaneously, the whole projectile force of which it is capable. Hence the quality of the powder must vary according to the nature of the piece in which it is used. With equal quantities of the ingredients the quality of the powder can still be altered, by using charcoal more or less carbonized, by giving the substance a greater or less degree of compactness, or by varying the size of the grain.

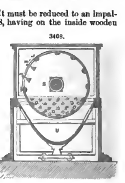
Before proceeding to study the manufacture of the various kinds of powder, we shall investigate the preparation of its primary components.

Saltpetre.—The saltpetre used in the manufacture of powder is the refined nitre. This nitre is remarkably pure, and rarely contains more than two or three thousandths of sea-salt. It comes from the refinery in very small crystalline grains, and in this state is used in the manufacture of powder.

3407.

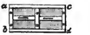


3408.



Sulphur.—Powder mills purchase the refined sulphur in rolls. It must be reduced to an impalpable powder, which is effected in wooden drums, Figs. 3407, 3408, having on the inside wooden brackets *a*, *b*, arranged along the edges of the cylinder. These drums are cylindrical, and about $1^{\mathrm{m}}\cdot10$ long, with a diameter of about $1^{\mathrm{m}}\cdot15$: they revolve on a horizontal iron axis O O′. Through a door *a b c d*, which is furnished with iron handles *m′ m*, the material is introduced. Pulverization is effected by means of small brass balls, of about 5 or 8 millimètres in diameter, of which each drum contains 150 kilogrammes: 30 or 40 kilogrammes of sulphur are added, and the drum is made to revolve for six hours, during which time the balls, rolling with the sulphur, crush it and reduce it to extreme fineness. In order to withdraw the sulphur, the door of the drum is removed, and replaced by a similar door *a b c d*, the panels of which are of wire gauze, Fig. 3409; by causing the drum to revolve five or six times, the sulphur escapes through this door, leaving the balls in the drum.

3409.



The powdered sulphur is sifted in a bolting machine, similar to that used for bolting flour; the particles which have not been sufficiently pulverized are thus separated, as well as any small grains of sand, which might occasion accidents in the manufacture of the powder.

The charcoal destined for the fabrication of powder must be most carefully selected. All kinds of wood are not suitable for the preparation of this charcoal: the tender and light woods, which yield a friable, porous charcoal, leaving very little ash, are preferred.

The woods most esteemed are the black alder and spindle-tree: poplar and chestnut may also be used. Hemp stalks, likewise, yield a very good charcoal.

The wood of the black alder is exclusively used in France. The branches of about 15 or 20 millimètres in diameter are preferred; and if larger branches are used, they are first split. The bark is always removed, as it gives too much ash. These branches are cut into lengths of from 1·5 to 2 mètres, and tied in bundles weighing from 12 to 15 kilogrammes.

The carbonization is never effected in kilns, as common charcoal is made, but in pits or in cylinders.

Carbonization in Pits.—Cylindrical pits, about $1^{\mathrm{m}}\cdot5$ in diameter and $1^{\mathrm{m}}\cdot2$ in depth, are excavated in the earth and lined with bricks, and filled with the wood, cut into pieces of $0^{\mathrm{m}}\cdot30$ in length, until the heap rises to the height of a few decimètres above the mouth of the pit. Fire is communicated through a hole at the bottom; and as the combustion advances, the branches are raised with a fork, so as to allow the fire to be regularly distributed. The pile gradually sinks, and fresh wood must be added to keep the pit full. When a flame is no longer seen, the mouth of the pit is hermetically closed by a sheet-iron lid, and the carbonization is then finished without access of air. The pit remains closed for three or four days, in order entirely to extinguish and cool the charcoal. It is then opened, the charcoal removed, and conveyed to the sorting room, where it is most carefully sorted by hand; such branches as have not been sufficiently carbonized and the half-burnt pieces are rejected, as also those which are too much carbonized, and therefore would make bad powder. The good charcoal should be used immediately, as it sensibly deteriorates by exposure to the moist air.

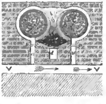
By carbonization in pits, about 18 to 20 per cent. of charcoal is obtained.

Carbonization in Cylinders.—This process yields a much larger proportion of charcoal; its quality is also more constant and uniform, because the fire can be regulated at will, and the carbonization can be arrested at the proper moment.

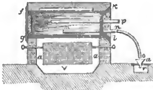
The cylinders C, C, Figs. 3410, 3411, are arranged in pairs in the same furnace: they are made of cast iron, having 2 mètres in length and about $0^{\mathrm{m}}\cdot70$ in diameter. One end of the cylinder is closed by a cast-iron lid, having four circular openings, through which pass four sheet-iron tubes, as *p q*, *m n*. Three of these tubes, which serve for the introduction of sticks of wood, are closed externally with wooden plugs, which can be withdrawn from time to time, so as to observe the progress of the carbonization. The fourth is open, and gives exit to the gases which are evolved during the process. A curved copper tube *n o* is fitted to one end of it, opening above a funnel *v*, which communicates with a horizontal canal T, ranging along the furnace and opening into the chimney. There are generally twelve furnaces arranged in the same mason-work.

The combustible is placed on the grate *d*, the flame and smoke ascend between the two cylinders, surround them, and descend by vertical pipes *u* and *u'* into a horizontal canal V V', which extends under all the furnaces, and opens into a chimney built in the middle of the room. The heat around each cylinder is regulated by registers *r* and *r'*, in the vertical pipes *u* and *u'*. The part *a b c* of the cylinders which is more immediately exposed to the action of the fire is covered with a luting of broken tiles and clay. The maximum of temperature is thus found at the top of the cylinders, favouring greatly the progress of the operation.

3410.



3411.



The sticks of wood to be carbonized are about 1m·5 in length: when the cylinders are filled with them, the movable end *f g h i* is replaced. This end is made of two sheets of iron, the space between which is filled with ashes; assay sticks are then introduced into the tubes *p q*, *m n*.

When the cylinders are charged, fire is kindled on the grate: turf is the fuel generally used. Active decomposition of the wood does not begin under four or five hours. The progress of the operation is estimated by the quantity and colour of the smoke which escapes from the pipe *n o*. When the carbonization is supposed to be advancing, the assay sticks are withdrawn, and an opinion formed from their appearance of the progress of decomposition in the various parts of the cylinders: if it be more advanced in some parts than in others, the combustible is pushed to the side where the carbonization is slowest. The heat is also regulated by the registers *r* and *r'*. In eleven or twelve hours, no vapour escapes any longer from the pipe *n o*; the operation is then terminated, the registers are closed, and the carbonization is completed without further aid. On the following day, the charcoal is withdrawn and placed in sheet-iron extinguishers (étouffoirs).

Carbonization in cylinders yields from 35 to 40 per cent. of charcoal, which is sorted by hand, and broken into small pieces.

The carbonization is not carried so far when the charcoal is intended for sporting powder: it is then withdrawn in the state of *red charcoal* (charbon roux); its colour then is brown. For war powder the carbonization is pushed further, to the state of *black charcoal* (charbon noir), called also *distilled charcoal*. Powder made with red charcoal would be too explosive for muskets or artillery.

Manufacture of Round Powder by the Bernese Process.—Blasting powder is made in France by a peculiar process, first used at Berne, whence it has obtained the name of *Bernese process*. This process is also applied to the manufacture of cannon and musket powder.

For blasting powder, the more highly-burned charcoal, which is unfit for other powder, is used: the great degree of calcination is in this case not injurious to the quality of the powder, as blasting powder should not possess too great an inflammability.

Six different operations may be distinguished in the manufacture—pulverization, mixing, graining, equalization, glazing, and drying.

The pulverization is effected by bronze balls in iron drums, exactly as has been previously described, with the only difference that at the same time balls of 4m·5 in diameter, and some varying from 7 to 15 mm., are used, the charcoal being more difficult to grind. The drum contains 120 kilogrammes of these balls, with 30 kilogrammes of sulphur and 27 of charcoal, which is the proportion for 150 kilogrammes of powder. The door is closed, and the drum made to revolve for four hours, at the rate of from twenty-five to twenty-eight revolutions a minute: the binary mixture, being then sufficiently ground, is removed from the drum.

The further mixture is then made as follows;—14·25 kilogrammes of the substance taken from the drum, exactly weighed, are placed in a barrel, and 23·25 kilogrammes of saltpetre added. Each barrel then contains 37·50 kilogrammes of the compound, namely;—

Saltpetre	23·25	62·0
Sulphur	7·50	20·0
Charcoal	6·75	18·0
	37·50	100·0

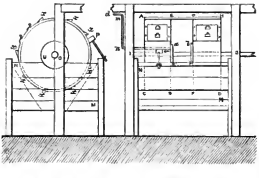
This compound is carried to the mixing machine, which are leather drums, containing 60 kilogrammes of bronze balls of 4mm·5 in diameter. The 37·50 kilogrammes of it are introduced, and the machine made to revolve at the rate of twenty-five or thirty revolutions a minute. After four hours' working, the compound is well mixed; the material is then conveyed into a main, and placed in barrels to be carried to the graining house.

The machine, Fig. 3412, used for the manufacture of round grains consists of two large oak drums A E G B, C H F D, 1m·75 in diameter, and 0m·63 in height. Each of them has only one entire end B E, C F: the opposite end A G, H D, being furnished with a circular opening U of

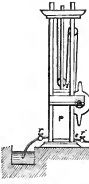
$0^{m}\cdot60$ diameter in the centre. The two drums are traversed by the same iron axes I O, supported between two strong vertical beams by two copper chains. Two copper discs *a a'*, *b b'*, fixed on the iron axis, connect the transverse iron axis I O with the ends E B and C F of the drum, while four strong cross-pieces, as A B, keep the whole steady. Each drum has a door M, of $0^{m}\cdot35$ by $0^{m}\cdot60$, closed with four copper screws, and used for introducing and withdrawing the material. All the lower part of the machine is surrounded by a large trough N, furnished with inclined copper planes, intended to receive the material when withdrawn by the doors, and conduct it into barrels placed beneath.

The drum A E G B is used for graining, and the other C H F D for glazing the powder.

3412.



3413.



The outer periphery of the granulator A E G B is furnished with twelve small cleats *x*, *x*, *x*, which, during the movement of the drum, move, and cause a small wooden hammer *p*, fastened by a cord to the side of the trough N, to strike constantly on its surface, detaching, by its blows, any portion of the material which might adhere to the drum. A copper watering tube *n u*, 2 centim. in diameter, and $0^{m}\cdot40$ in length, having one side pierced with very minute holes, enters the granulating machine, a little above its axis, and communicates, by a curved copper tube *n m s*, with a forcing pump. This pump, Fig. 3413, is composed of a copper pump-tree P, in which a perfectly well-fitting piston moves: an iron rod *t t'*, fastened to the upper part of the piston, works between two wooden uprights. The piston is set in motion by means of a winch and a rope which passes over a pulley fixed to the iron rod. The lower part of the pump-tree communicates, on the one hand, with a reservoir of water, and, on the other, with the injecting tube *s m n u*; two stopcocks *r*, *r'*, closing at will the communicating tubes. When the stopcock *r* is opened and the piston raised, the lower part of the pump fills with water; if this stopcock be closed and that at *r'* opened, the piston descends by its own weight, allowing the water to escape through the watering tube *s m n u*.

In order to introduce a charge of the material, the workman removes the door M of the granulating machine, and pours in 100 kilogrammes of powder already grained, called the *nucleus* (noyau), the origin of which will be hereafter explained; he replaces the door, and sets the machine in motion at the rate of ten revolutions a minute. During this motion, the first sprinkling of 5 per cent. of water is made; the fluid thus wetting the nucleus which occupies the lower part of the granulating machine in the form of a fine rain, and the rotary motion of the drum constantly renewing the surface, all the grains are uniformly moistened.

When the first sprinkling is over, he introduces through the opening U 50 kilogrammes of the mixture as it comes from the mixing machine, inserting 1 kilogramme at a time with a wooden shovel, spreading it as evenly as possible in the drum. The movement of the machine rolling the damp grains constantly among the dry meal powder causes the latter to adhere to their surface, and each grain thus to increase by concentric layers.

Immediately after, a second sprinkling is made, and then 50 kilogrammes of the ternary mixture are gradually added. After allowing the machine to revolve for a quarter of an hour, the workman ascertains if the meal powder is entirely absorbed; he then empties the machine, by dropping the material into barrels placed underneath. These operations last from thirty-five to forty minutes.

The material, when taken from the machine, is composed of variously-sized grains, which require to be separated, or *equalized*. This is done by shaking the grains over two leather sieves; the first, called the *equalizer* (égalisoir), separates those grains which are too large, while the second, the *sub-equalizer*, allows those which are too fine to pass through. The holes in the equalizer are $3^{mm}\cdot4$ in diameter. The grains and irregular pieces which do not pass through are set aside; those which pass through are sifted on the sub-equalizer, the holes of which are $1^{mm}\cdot2$ in diameter. There remain on the latter sieve those grains the diameter of which is comprised between $1^{mm}\cdot2$ and $3^{mm}\cdot4$, and which are suitable for blasting; they are deposited in a barrel to undergo a subsequent operation. All which passes through the sub-equalizer is composed of grains smaller than $1^{mm}\cdot20$; it is considered as a *nucleus*, because this grain need only be increased in the granulating machine to make it of the proper size. As each operation yields the quantity of nucleus necessary for a succeeding operation, it is sufficient to obtain some for the first operation, for which the angular powder, of the size of musket powder prepared in the stamping machine, is employed. The grains which are too large, and the irregular pieces which remained on the equalizer, are broken by means of the cake, and used as a nucleus for the succeeding operation.

Blasting powder is glazed as well as sporting powder, in order to increase its density. This operation is effected in the second drum C H F D. 200 kilogrammes of equalized grains are introduced, and it is turned for four hours; by direct experiment it is ascertained when the grain has acquired sufficient density. For this purpose 60 grammes of the glazed grains are poured into a graduated test-glass; the grain is considered as sufficiently glazed when the level of the material rises to a certain division in the instrument. The glazed grain is dried in the ordinary way.

Round war powder is manufactured by the same method, the usual proportion of the ingredients for war powder, 25 of saltpetre, 12·5 of sulphur, and 12·5 of charcoal being employed. Two kinds of equalized grains are separated; those of which the diameter is between $1^{\text{mm}}\cdot 2$ and $2^{\text{mm}}\cdot 1$ constituting cannon powder; and musket powder, the diameter of the grains of which varies from $1^{\text{mm}}\cdot 0$ to $1^{\text{mm}}\cdot 20$.

Analysis of Powder.—The analysis of powder is a tedious and delicate operation, when the proportions and nature of its components are to be ascertained very exactly. The first operation is to determine the proportion of hygrometric water the powder contains, for which purpose a known weight of powder is exposed for several days in a dry vacuum, and the loss it experiences ascertained; or else the substance is placed in a U-shaped tube, kept at a temperature of 60° or 70°, and traversed by a current of dry air.

Ten grammes of dry powder are then treated with hot water, which dissolves the nitrate of potassa. The insoluble residue, composed of sulphur and charcoal, is collected on a small filter, which has been previously dried and weighed. When this residue has been properly washed, it is dried with the filter at a moderate temperature, and weighed; by subtracting from this weight that of the filter above, the weight of the sulphur and charcoal is obtained. After separating, as carefully and completely as possible, the substance from the filter, it is again weighed in a small bottle and treated with sulphuret of carbon, which may be mixed with an equal volume of ether, without too much impairing its solvent power. The charcoal which remains isolated is collected on a small filter previously dried, and weighed after a second desiccation, after having been well washed in a mixture of sulphuret of carbon and ether. The weight of the sulphur is thus obtained by the difference. It may, however, also be weighed directly after evaporating, at a low temperature, the solvent which contains it. The charcoal of the powder is not pure carbon; it contains, as the carbonization is always imperfect, a considerable proportion of oxygen and hydrogen; but, as the chemical nature of the charcoal exerts great influence on the quality of the powder, it is important, in an accurate analysis, to ascertain the amount of carbon exactly. An idea may be formed of the composition of charcoal by the following numbers, obtained from the analysis of the red charcoal used in the manufacture of sporting powder;—

Carbon	71·42
Hydrogen	4·85
Oxygen and nitrogen	22·91
Ashes	0·82
	100·00

The quantity of sulphur contained in powder may also be determined by operating directly on the powder itself. To effect this 10 grammes of dry powder are dissolved in a small quantity of hot water, nitric acid is added, and, after allowing the fluid to boil, small quantities of chlorate of potassa are gradually introduced. Under the influence of these oxidizing agents the sulphur is dissolved in the state of sulphuric acid, which is precipitated, after the liquid is filtered, by chloride of barium. The precipitate is allowed to settle, the clear liquid poured on a filter, and the precipitate, after being boiled for a few moments with chlorohydric acid, to dissolve the nitrates it might contain, is collected on the same filter and weighed after calcination.

Ten grammes of dry powder may also be mixed with an equal weight of nitrate of potassa and four or five times its weight of chloride of sodium; the mixture being thrown, in small quantities at a time, into a platinum crucible, deflagrates slowly, without any loss of the material. It is subsequently treated with water, and the sulphuric acid is precipitated by chloride of barium, after supersaturating the liquid with chlorohydric acid.

It has also been proposed to dissolve the sulphur of the mixture of sulphur and charcoal, by a solution of monosulphide of sodium, or of hyposulphite of soda; but this process is useless, because the charcoal, being always considerably attacked by these alkaline liquids, gives off a peculiar acid, called *ulmic acid.*

Very frequently only the quantity of saltpetre contained in powder is to be ascertained. This is easily done by treating 50 grammes of powder with 200 grammes of hot water, and filtering the liquid into a test-glass having a mark at the level corresponding to 500 cubic centimètres. The material is washed with water on a filter until the filtrate reaches the level. The liquid is then cooled to 60°, the contraction it undergoes by cooling being compensated by the addition of a small quantity of water; it is then well shaken to render it homogeneous, and a peculiar areometer, graduated so that its level will mark immediately the hundredths of nitrate of potassa contained in the 50 grammes of powder, is dipped in. In this manner the proportion of nitrate of potassa may easily be determined, to very nearly a half-hundredth.

Gun-cotton.—The chemical constitution of gun-cotton has been conclusively established by the researches of Hadow. In the formation of substitution-products by the action of nitric acid upon cotton or cellulose, three atoms of the latter appear to enter together into the chemical change, and the number of atoms of hydrogen replaced by peroxide of nitrogen in the treble atom of cellulose $C_{18}H_{30}O_{15} = 3(C_6H_{10}O_5)$ may be nine, eight, seven, or six, according to the degree of concentration of the nitric acid employed.

The highest of these substitution-products is trinitro-cellulose, pyroxilin, or gun-cotton—$C_{18}\left\{\begin{matrix}H_{21}\\9NO_2\end{matrix}\right\}O_{15} = 3\,C_6\left\{\begin{matrix}H_7\\3NO\end{matrix}\right\}O_5$; this being the substance first produced by Pelouze in an impure condition, in 1838, by the action of very concentrated nitric acid upon paper, or fabrics of cotton or linen, and afterwards obtained in a purer form by Schönbein, who employed a mixture of concentrated nitric and sulphuric acids for the treatment of cotton-wool; the object of the sulphuric acid being to abstract water of hydration from the nitric acid, and also to prevent the action of the nitric acid from being interfered with by the water which is produced as the chemical transformation of the cotton into gun-cotton proceeds. The formation of trinitro-cellulose is represented by the following equation;—

$$C_6H_{10}O_5 + 3\left\{\begin{matrix}H\\NO_2\end{matrix}\right\}O = C_6\left\{\begin{matrix}H_7\\3NO_2\end{matrix}\right\}O_5 + 3\left\{\begin{matrix}H\\H\end{matrix}\right\}O.$$

Cotton. Nitric Acid. Gun-cotton. Water.

The lowest substitution-product for cotton, of those named above, appears to have the same composition as the substance which Braconnet first obtained in 1832, by dissolving starch in cold concentrated nitric acid, and adding water to the solution, when a white, highly-combustible substance is precipitated, to which the name of *Xyloïdin* was given. The substitution-products from cotton, intermediate between the lowest and highest, are soluble in mixtures of ether and alcohol, and furnish by their solution the important material *collodion*, so invaluable in connection with photography, surgery, experimental electricity, and so on.

According to Schönbein's original prescription, the cotton was to be saturated with a mixture of one part of nitric (sp. gr. 1·5) and three parts of sulphuric acid (sp. gr. 1·85), and allowed to stand for one hour. In operating upon a small scale, the treatment of cotton with the acid for that period is quite sufficient to effect its complete conversion into the most explosive product *pyroxilin*, or *trinitro-cellulose*; but when the quantity of cotton treated at one time is considerable, especially if it is not very loose and open, its complete conversion into pyroxilin is not effected with certainty unless it be allowed to remain in the acid for several hours. This accounts in great measure for the want of uniformity observed in the composition of gun-cotton and its effects as an explosive in the earlier experiments instituted; and it is moreover very possible that the want of stability and consequently even some of the accidents which it was considered could only be ascribed to the spontaneous ignition of the material, might have been due to the comparatively unstable character of the lower products of substitution, some of which existed in the imperfectly-prepared gun-cotton.

The system of manufacture of gun-cotton elaborated by General von Lenk is founded upon that described by Schönbein; the improvements which the former has adopted all contribute importantly to the production of a thoroughly uniform and pure gun-cotton; there is only one step in his process which is certainly not essential, and about the possible utility of which chemical authorities are decidedly at variance with General von Lenk.

The following is an outline of the process of manufacture of gun-cotton as practised by Lenk. See ATOMIC WEIGHTS. The cotton, in the form of loose yarn of different sizes, made up into hanks, is purified from certain foreign vegetable substances by treatment for a brief period with a weak solution of potashes, and subsequent washing. It is then suspended in a well-ventilated hot-air chamber until all moisture has been expelled, when it is transferred to air-tight boxes or jars, and at once removed to the dipping tank, or vessel where its saturation with the mixed acid is effected. The acids of the specific gravity prescribed by Schönbein are very intimately mixed in a suitable apparatus in the proportions originally indicated by that chemist; that is, three parts by weight of sulphuric acid to one of nitric acid. The mixture is always prepared some time before it is required, in order that it may become perfectly cool. The cotton is immersed in a bath of the mixed acids, one skein at a time, and stirred about for a few minutes, until it has become thoroughly saturated with the acids; it is then transferred to a shelf in this dipping trough, where it is allowed to drain, slightly pressed to remove any large excess of acid, and afterwards placed in an earthenware jar, provided with a tightly-fitting lid, which receives six or eight skeins, weighing from 2 to 4 oz. each. The cotton is tightly pressed down in the jar, and if there be not sufficient acid present just to cover the mass, a little more is added: the proportion of acid to be left in contact with the cotton being about 10½ lbs. to 1 lb. of the latter. The charged jars are set aside for forty-eight hours in a cool place, where they are kept surrounded by water to prevent any elevation of temperature and consequent destructive action of the acids upon the gun-cotton. The same precaution is also taken with the dipping trough, as considerable heat is generated during the first saturation of the cotton with the acids. At the expiration of forty-eight hours the gun-cotton is transferred from the jars to a centrifugal machine, by the aid of which the excess of acid is removed as perfectly as is possible by mechanical means, the gun-cotton being afterwards only slightly moist to the touch. The skeins are then immersed singly in water, and moved about briskly, so as to become completely saturated with it as quickly as possible. This result is best accomplished by plunging the skeins under a fall of water, so that they become at once thoroughly drenched. If they are simply thrown into the water and allowed to remain at rest, the heat produced by the union of a portion of the free acids with a little water would be so great as to establish at once a destructive action upon the gun-cotton by the acid present. The washing of the separate skeins is continued until no acidity can be detected in them by the taste; they are then arranged in frames or crates and immersed in a rapid stream of water, where they remain undisturbed for two or three weeks. They are afterwards washed by hand to free them from mechanical impurities derived from the stream, and are immersed for a short time in a dilute boiling solution of potashes. After this treatment, they are returned to the stream, where they again remain for several days. Upon their removal they are once more washed by hand, with soap if necessary; the pure gun-cotton then only requires drying by sufficient exposure to air at a temperature of about 27° C. to render it ready for use. A supplementary process is, however, adopted by General von Lenk, about the possible advantage or use of which his opinion is not shared by others. This treatment consists in immersing the air-dried gun-cotton in a moderately strong hot solution of soluble glass (silicate of potassa or soda) for a sufficient period to allow it to become completely impregnated, removing the excess of liquid by means of the centrifugal machine, thoroughly drying the gun-cotton thus silicated, and finally washing it once more for some time until all alkali is abstracted. Lenk considers that by this treatment some silica becomes deposited within the fibres of the gun-cotton, which, on the one hand, assists in moderating the rapidity with which the material burns; and, on the other hand, exercises (in some not very evident manner) a preservative effect upon the gun-cotton, rendering it less prone to undergo even slight changes by keeping. The mineral matter contained in pure gun-cotton which has not been submitted to this particular treatment amounts to about 1 per cent. The proportions found in specimens which have been silicated in Austria and in this country, according to Lenk's directions, vary between 1·5 and 2 per cent. It is difficult to understand how the addition of 1 per cent. to the mineral matter, in the form chiefly of silicate of lime and magnesia, the bases being derived from the water used in the final washing, which are deposited upon and between the fibres in a pulverulent form, can influence to any material extent either the rate of combustion or the keeping qualities of the product obtained by Lenk's system of manufacture.

Gun-cotton prepared according to the system just described is exceedingly uniform in composition. The analyses prepared both in Austria and at Waltham Abbey have furnished results corresponding accurately to those required by the formula $C_6\left\{\begin{matrix}H\\3\,NO_2\end{matrix}\right\}O_5$. In its ordinary air-dry condition it contains, very uniformly, about 2 per cent. of moisture—an amount which it absorbs rapidly from the air when it has been dried. The proportion of water existing in the purified air-dried cotton, before conversion, is generally about 6 per cent. When pure gun-cotton is exposed to a very moist atmosphere or kept in a damp locality, it will absorb as much as from 6 to 7 per cent.; but if it be then exposed to air of average dryness, it very speedily parts with all but the 2 per cent. of moisture which it contains in its normal condition. It may be preserved in a damp or wet state apparently for an indefinite period without injury; for if afterwards dried by exposure to air, it exhibits no signs of change.

The general properties of gun-cotton as an explosive agent have long been popularly known to be as follows:—When inflamed or raised to a temperature ranging between 137° and 150° C., it burns with a bright flash and large body of flame, unaccompanied by smoke, and leaves no appreciable residue. It is far more readily influenced by powerful percussion than gunpowder; the compression of any particular portion of a mass of loose gun-cotton between rigid surfaces will prevent that part from burning when heat is applied. The products of combustion of gun-cotton in air redden litmus paper powerfully; they contain a considerable proportion of nitric oxide, and act rapidly and corrosively upon iron and gun-metal. The explosion of gun-cotton when in the loose, carded condition—the form in which it was always prepared in the early days of its discovery—resembles that of the fulminates in its violence and instantaneous character. In the open air it may be inflamed when in actual contact with gunpowder without igniting the latter; in a confined space, as in a shell or in the barrel of a gun, the almost instantaneous rapidity of its explosion produces effects which are highly destructive as compared with those of gunpowder, while the projectile force exerted by it is comparatively small.

In 1864 the members of a committee appointed by Government examined a number of miners on the question of the relative advantages of gunpowder and gun-cotton when the latter was used in the form of hollow rope. The conclusion arrived at was, that gun-cotton was superior to gunpowder, especially when used in solid rocks; but that, taking into consideration the respective prices of the two materials, the extra care required with the cotton, and the injurious effects from inhaling its vapours, it was not the more useful of the two.

Experiments were, however, made by Thomas Sopwith and F. A. Abel, in 1865, with gun-cotton made from *pulp*.

The gun-cotton used in the experiments was in two forms, granulated and compressed.

The granulated gun-cotton was prepared from gun-cotton pulp, by mixing it, when dry, with 10 per cent. of its weight of gum arabic, dissolved in sufficient water to render the gun-cotton operated upon at one time just wet to the touch; after which the material was shaken for some time in a drum. By this treatment the gun-cotton assumes a granulated form; the globular grains produced vary in size between that of coarse small-arm powder and the coarsest form of blasting powder.

The compressed gun-cotton consisted of square pieces measuring from ¾ to ½ in. across, and ⅛ to ½ in. in thickness. These were obtained by cutting up slabs of gun-cotton, prepared from pulp compressed to a density of about 50 lbs. the cubic foot.

The gun-cotton was sent to Allenheads, for the experiments, in the form of 1 oz. and ½ oz. charges, contained in cylindrical pasteboard cases of 1 in. diameter and upwards.

The mode of charging the holes was varied somewhat with the direction in which these were bored. If they were vertical, or bored at an angle inclining downwards, the paper case containing the charge was inserted into the opening—a size being selected which fitted loosely into the latter—and the gun-cotton was allowed to fall into the hole, the case being gently shaken and squeezed to aid the exit of the charge. If the inclination of the hole was inconsiderable, it was necessary to push down the gun-cotton occasionally by means of a wooden rod, especially when the granulated form was employed. Holes which were horizontal, or had an inclination upwards, were more difficult to charge. A contrivance prepared for this purpose, but which was not sufficiently long for the horizontal holes in these particular experiments, consisted of a slightly conical tin tube about 12 in. long, the external diameter of one end being 1¼ in., and of the other ¾ in. The narrow opening of this tube was plugged with a small piece of cotton wool, and the charge of gun-cotton was poured in at the other end. This wide end was afterwards inserted into the hole, the tube being passed into the latter as far as possible, and the charge was then pushed out of the tube by means of a wooden rod which fitted tightly into the narrow or outer end of the tin tube. This arrangement is similar in its nature to the measure used by the miners for charging the holes with powder, and, if made of sufficient length, would probably remove the difficulty which was experienced in charging the horizontal holes.

All the holes were fired with the ordinary miner's safety fuze, which was inserted before the entire charge was introduced, as is the practice in blasting with gunpowder.

After the charge was inserted into the holes and pressed down with the wooden rod, a plug of cotton waste was pushed down, for the purpose of carrying to the bottom any particles of the gun-cotton clinging to the sides of the hole. The latter was afterwards tamped, as usual, first with clay, and afterwards with débris of limestone in a nearly powdered state.

The experiments in the mines were tried in the upper part of the Great Limestone in East Cross Vein. The stone is very hard.

All the holes were nominally 1¼ in. in diameter. Some of them, in the hard limestone, tapered considerably, and would hardly have received 1-in. gun-cotton rope throughout their entire length.

Experiments at Thorn Green Quarry, Allenheads.—Eight holes were experimented upon in this quarry. The first three were vertical holes bored in ledges left by previous operations, about 2 ft. from the face of the ledge. They were numbered 1, 2, and 3, but were fired in reverse order, so that the work might be equalized, No. 3 being nearest the side face of the ledge, and No. 1 farthest from it, but about equally near to a flaw in the limestone.

No. 3 was 14 in. deep. It was charged with 6 in. of 1¼-in. gun-cotton rope (= 1·56 oz.), which left 8 in. for tamping. The proportion of gun-cotton used was that which the quarrymen had been in the habit of employing for similar holes. The face was well opened up by the explosion, and the work done pronounced highly satisfactory.

No. 2, 14½ in. deep, which now had a side face similar to that of No. 1, was charged with 1·5 oz. of the compressed gun-cotton, which left 8½ in. for tamping. The report of this explosion was more violent than in the case of No. 3; pieces of the stone were thrown into the air to a great height, and the rock was very much broken up all round the hole. There was decidedly more work done than by the former explosion, and fissures were produced running back in the ledge to a considerable distance. The charge of the gun-cotton used was evidently in excess of the work to be accomplished.

No. 1 hole, 14 in. deep, was charged with 1 oz. of the granulated gun-cotton, leaving 7 in. for tamping. In this instance the rock was well broken in all directions, and beyond the depth of the hole; large blocks were perfectly separated, and though not thrown off to any important extent, were readily removed by the men. The work to be performed by this explosion was perfectly accomplished, and apparently with a well-proportioned amount of powder.

No. 4 hole was vertical, 17 in. deep, and 2 ft. 4 in. from the face. It was a difficult hole, being in the midst of very solid rock. The men proposed to employ 8 in. of 1¼-in. rope for the hole (= 2·08 oz.), and they would have used 8 oz. of gunpowder. It was charged with 1·5 oz. of the granulated gun-cotton, leaving 6 in. for tamping. The work done by the explosion was pronounced by the quarrymen to be not only complete, but in excess of what they would have expected, from their usual experience: a mass of rock, 4 ft. by 2 ft. 4 in., and 14 in. thick, was blown off the front of the face; the latter was fissured in several places to a depth of about 4 ft. 6 in., and one fissure extended backwards, at right angles to the face, about 4 ft. in length.

No. 5 hole, vertical, was 18½ in. deep, and 2 ft. 2 in. from the face. It was very similar in position to No. 4 hole, and considered to present about the same work to be accomplished. It was charged with 1 oz. of the compressed gun-cotton, which left 14 in. for tamping. The work done was very similar, and pronounced fully equal to that performed by the 1·5 oz. of granulated gun-cotton in the preceding experiment.

No. 6 hole, vertical, 14 in. deep and 2 ft. from the face, appeared somewhat weaker than the two preceding ones, as the face of the rock exhibited two flaws, one on either side of the hole, about 1 ft. and 18 in. to the right and left. It was charged with ½ oz. of compressed gun-cotton; the tamping amounted to 12 in. Two wide fissures were produced in the face, by the explosion, to a depth of about 5 ft., and some fissures (one about 4 ft. long) were produced towards the back of the ledge. The masses of rock detached by this operation, which admitted of removal by the workmen, appeared nearly equal in quantity to the work done in the two preceding operations. The quarrymen were greatly astonished at the work done with the ½ oz. of material, in a position where they would have employed at least 6 oz. of gunpowder.

No. 7. This was a horizontal hole, 30 in. deep, in the face of a ledge of the limestone. The distance of the hole from the upper surface or ledge was 3 ft. The total width of solid rock to the right and left of the hole was 5 ft., there being a vertical fissure on the one side about 2 ft. 5 in. from the hole. There was also a horizontal flaw, near the base, in the block of rock to be operated upon. The hole was considered a very strong one by the men. They proposed to employ 10 oz. of powder, or 12 in. of 1¼-in. gun-cotton rope (= 3·12 oz.). The hole was charged with 1 oz. of granulated gun-cotton, leaving 23 in. for tamping. By the explosion a large block of the rock, constituting the principal mass of the ledge, situated above the hole, was detached and moved forward some distance, so that it was easily thrown off by the workmen; in addition, a smaller block, considerably to the left of the hole, was detached, and the rock was broken up beneath the hole, so that a considerable quantity could be easily removed. The amount of stone detached by this operation, with 1 oz. of the granulated gun-cotton, was about 53 cub. ft.

No. 8. This was a hole, 26 in. deep, driven at a slight angle into a face of the rock which had not yet been operated upon. The height of the face above the hole was about 6 ft., and the undisturbed surface soil was above it. It was charged, in the first instance, with 1 oz. of compressed gun-cotton, the tamping occupying 23½ in. of the hole. The explosion blew only about 2 in. off the mouth of the hole, but produced vertical fissures, extending to some distance above and below the hole. This hole was afterwards re-charged with 2 oz. of compressed gun-cotton, the explosion of which considerably increased the fissures, but the mass of rock was so closed in upon all sides, excepting the face, that a more considerable charge than 2 oz. would evidently have been required in the first instance (when the rock was quite sound) to effect any important dislodgment. After the second charge, the hole was too unsound for further experiments.

Experiments in the Mines at Allenheads.—There is some difficulty in forming an accurate estimate of the comparative work done, by different charges of gun-cotton or gunpowder, in the confined space of a drift, or other similar locality; and the debris of previous blasting operations sometimes render it scarcely possible to estimate correctly the work accomplished.

The following is a brief statement of the most definite observations made:—

Ten holes had been previously prepared and were operated upon. In three cases of what was pronounced to be difficult work, the holes had been driven either in a horizontal or slightly sloping direction into the perfectly sound rock, in positions where no weakness had been induced by previous blasts. The work accomplished by the compressed gun-cotton was pronounced excellent; the rock being removed up to the extremity of the holes. In one of these experiments, in a hole 13 in. deep, 1½ oz. of compressed gun-cotton were used, leaving 7 in. for the tamping. In another hole, 11 in. in depth, ½ oz. of compressed gun-cotton, with 8 in. of tamping, performed the work allotted to it perfectly. In a third hole, 16 in. deep, at the base of the rock, quite apart from previous blasting operations, 2 oz. of the compressed gun-cotton were used, leaving 12 in. for tamping. The rock was cleanly detached to the base of the hole. The miners stated that the usual charge of gunpowder for a hole of this kind (about 8 oz.) would not have been likely to do any useful work, the position of the hole being a very difficult one.

Another hole of the same depth as the last, and similarly situated, was charged with only 1 oz. of the compressed material. In this instance a length of 10 in. of the hole was blown away with the surrounding rock, leaving 6 in. undestroyed.

A hole, 15 in. deep, driven almost horizontally into the rock, was also charged with 1 oz. of compressed gun-cotton. In this instance, again, a portion of the hole was not blown away, but this result may have been, to some extent, due to an unsoundness of the hole at the base, which was discovered after the explosion.

Four holes were operated upon, which were known to be unsound (that is, to pass into cavities or fissures of more or less considerable size). Two of these, each 12 in. deep, which were pronounced very unsound, were charged with 1 oz. of the granulated gun-cotton. In both instances, the gases resulting from the ignition of the gun-cotton escaped through the fissures in the rear, and there was no destruction. (The same kind of failure took place on several occasions, with the employment of both gun-cotton rope and gunpowder, when the committee operated upon unsound holes at this place in October, 1864.)

A third hole, 14 in. deep, and unsound at the base, was charged with 1½ oz. of compressed gun-cotton, and 9 in. of tamping. On this occasion, the work done was pronounced good, the rock being blown away to within 4 in. of the bottom of the hole.

The fourth hole, 12 in. deep, in which the unsoundness was less obvious than in the preceding three, was charged with 1 oz. of granulated gun-cotton, leaving 7 in. of the hole for tamping. The work allotted to this hole was perfectly accomplished, the rock being cleared to the base of the hole.

These trials of gun-cotton charges prepared from the pulp, though insufficient to furnish conclusive results as regards the merits of the explosion, when employed in a granulated form, nevertheless afford sufficient experimental evidence to warrant the following statements;—

1. The *granulated* gun-cotton pulp (not compressed) appears decidedly more effective as a blasting material than an equal weight of gun-cotton in the form of rope. This result is to be ascribed mainly to the greater rapidity of explosion of the gun-cotton when in the form of light granules; it may also, in some measure, be due to the circumstance that, in a hole charged with gun-cotton in the form of grains, or small fragments, the charge is in close contact on all sides with the rock, which is not the case when gun-cotton rope is employed, unless the hole is perfectly cylindrical, which it very seldom is. This remark as to the irregular shape of the holes does not apply to those made by the boring apparatus of Percy Westmacott, which has been partially in use at Allenheads Mines, and by which a perfectly cylindrical hole is effected. The operation of this machine was witnessed by the committee in 1864, but it has not yet been brought into continuous use.

This form of the material occupies a little more space in a hole than an equivalent weight of gun-cotton rope; this circumstance may perhaps somewhat lessen the full destructive power of the granulated gun-cotton; but a careful comparison of results is yet needed before a definite opinion can be expressed on this point.

2. The *compressed* gun-cotton, in the form of small lozenge-shaped fragments, exhibited a superiority in destructive power over the granulated gun-cotton, which may be ascribed to the fact of its occupying less space, and therefore affording room in a hole for a proportionately large amount of tamping, and also bringing the destructive agent well in rear of the work to be performed. The superiority of the gun-cotton in this form over charges of gun-cotton rope, as regards the comparative amount of work done by equal weights of the two, appears unquestionable.

3. No decided evidence was obtained of a superiority of the granulated and the compressed gun-cotton over gun-cotton rope, when employed in *unsound* holes.

4. The charging of holes, the position of which was horizontal, or nearly so, with gun-cotton in

the form of granules or small fragments, presented difficulties, to overcome which, special mechanical appliances would have to be used if the gun-cotton be introduced into the hole without an envelope. There is also considerable risk, under these circumstances, of small fragments of the gun-cotton becoming lodged on the sides of the hole, unless their removal can be ensured by carefully cleaning the holes with plugs of cotton waste, hemp, or soft paper, before the tamping is proceeded with. The charges might, however, be inserted into holes in thin paper cases, which would obviate the difficulties and possible risk attending the charging of the holes, though it would probably do away, to some extent, with the advantage resulting from the tendency of the granulated gun-cotton, when employed without a case, to accommodate itself to any irregularity in the shape of the hole.

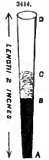
It has been found that the explosive force of gun-cotton may, like that of nitro-glycerine, be developed by the exposure of the substance to the sudden concussion produced by a detonation; and that if exploded by that agency, the suddenness and consequent violence of its action greatly exceed that of its explosion by means of a highly-heated body or flame. This is a most important discovery, and one which invests gun-cotton with totally new and valuable characteristics; for it follows, as recent experiments have fully demonstrated, that gun-cotton, even when freely exposed to air, may be made to explode with destructive violence, apparently not inferior to that of nitro-glycerine, simply by employing for its explosion a fuze to which is attached a small detonating charge.

The mode of operation is as follows;—

The detonating substance is placed in a tin tube of the dimensions shown, Fig. 3414, and it occupies in the inside of the tube the space from A to B.

On this at C is placed a small plug of gun-cotton, and the rest of the tin tube from C to the open end at D is empty.

3414.



Before leaving the manufactory a small piece of paper is pasted on the end merely to prevent anything falling into it, and this paper, so long as it remains, serves to distinguish the charged or useful primers, as the tin tubes are called, from empty tubes.

It is in this form that the detonating primers are supplied from the manufactory.

These primers are, in fact, large percussion caps, and are to be handled with care, as also to be protected from fire, and from all violent concussion. They explode with some violence when ignited, or if struck a violent blow, but with reasonable care are quite harmless, as much so as ordinary percussion caps for fowling-pieces. They may not only be safely handled, but may be thrown about with any freedom short of actual and intentional violence. Even when thrown on the ground or allowed to fall from a height of 20 or 30 ft., they are in no way affected by such usage.

When the primer is to be used, the paper cover at D is removed, and an ordinary fuze is then inserted, so as to be in contact with the gun-cotton at C. The tube is made large enough to receive an ordinary fuze, and as soon as the insertion has been made, the tube is pressed close to the fuze by a pair of common pliers.

This preparation is most conveniently done before entering a mine, but there is nothing to prevent its being done in a mine or quarry at any time.

The charges of compressed gun-cotton are made with a circular hole to receive the fuze. Into this hole the small end of the tin primer is inserted, instead of the fuze, and this is the only difference in the mode of firing as compared with the usual mode of exploding gun-cotton with a fuze.

It is important to observe that when the primer is thus used for blasting, it is not necessary to fill up the hole by any stemming or tamping; the hole may be left perfectly open, and those who know how often accidents occur in the process of stemming or tamping will at once appreciate the saving of time and the amount of personal safety thus obtained.

In the case of failure of explosion, accidents often occur from the miners attempting to remove the stemming material. All this is avoided, as after a proper interval of time the fuze with the primer attached can be safely and easily withdrawn from the open bore-hole.

Some remarkable results have been already obtained with this new mode of exploding gun-cotton. Large blocks of granite and other very hard rock, and iron plates of some thickness, have been shattered by exploding small charges of gun-cotton, which simply rested upon their upper surfaces—an effect which will be sufficiently surprising to those who have hitherto believed, as everyone has believed, that unconfined gun-cotton was scarcely to be considered as explosive at all, that it puffed harmlessly away into the air, not exerting sufficient force upon the body on which it might be resting to depress a nicely-balanced pair of scales, supposing the charge to be fired upon one plate of the scale. Further, long charges or trains of gun-cotton, simply placed upon the ground against stockades of great strength, and wholly unconfined, have been exploded by means of detonating fuzes placed in the centre or at one end of the train, and produced uniformly destructive effects throughout their entire length, the results corresponding to those produced by eight or ten times the amount of gunpowder when applied under the most favourable conditions. Mining and quarrying operations with gun-cotton applied in the new manner have furnished results quite equal to those obtained with nitro-glycerine, and have proved conclusively that if gun-cotton is exploded by detonation it is unnecessary to confine the charge in the blast-hole by the process of hard-tamping, as the explosion of the entire charge takes place too suddenly for its effects to be appreciably diminished by the line of escape presented by the blast-hole, some loose sand or broken rubbish to hold the fuze in position being all that is required. Thus the most dangerous of all operations connected with mining may be dispensed with when gun-cotton fired by the new system is employed.

Abel and Sopwith, in their report upon the use of gun-cotton with the detonating primer, give the following as an illustration of the different results obtained by the use of the primer as compared with the explosion of gun-cotton by an ordinary fuze;—A disc of gun-cotton, weighing 1 oz., was laid upon a large slab of sandstone, fired by means of the ordinary fuze; it merely ignited with a sudden burst of flame, without much noise, entirely without violence, and quietly burnt away in about thirty seconds, doing no injury whatever to surrounding substances; but when the same quantity of gun-cotton of the same quality was laid on the same stone, and fired by means of a detonating primer, the whole mass instantaneously exploded with a report as loud as a cannon, and with an amount of destructive energy which could with difficulty be understood by any who had not quietly seen and carefully examined the result; not only was the stone shattered and broken into many pieces, but those portions of it which were immediately under the charge were literally ground and crushed into sand.

It will readily be observed that this discovery, which we believe is due to Mr. Brown, of the War Office Chemical Establishment, is likely to be attended with the most important results. Not merely is the strength of gun-cotton exploded in this way much greater than that of the same substance fired by simple ignition, but it now operates under conditions which were sufficient under the old system practically to deprive gun-cotton of its power.

See Boring and Blasting. Quarrying.

GUN MACHINERY, Rifled. Fr., *Machine à rayer les canons de fusil, ou les bouches à feu;* Ger., *Ziehbank für Geschütze;* Ital., *Macchina da rigare;* Span., *Máquina de estriar les cañones.*

John Anderson, writing in P. I. M. E., 1862, observes that in the manufacture of guns, more especially of rifled cannon, one great object is to have the bore of definite dimensions, perfectly straight and parallel. The difficulty of accomplishing this depends entirely on what is considered straightness or parallelism, and on the closeness of measurement which may be adopted. With reference to dimensions: if the bore were completed in its boring up to the exact size previous to rifling, it would, from the rubbing of the rifling block and the rusting and cleaning after proof, be considerably over the size when actually finished. Hence it is found necessary to bore only up to within $\frac{3}{1000}$ of an inch of the proper dimensions, and two plug-gauges are employed for the purpose, one $\frac{3}{1000}$ of an inch under the proper size and the other exactly the proper size; the first is 12 in. long and must pass through the bore like the plug in the Whitworth gauge, while the other should not enter. In working so near there is much liability of exceeding the dimensions; hence the entrance for the final boring tool is made from the muzzle end, where an enlargement is of the least consequence. In the preparation of instruments for such precise boring it is found in practice that adjustable cutters are the most economical and convenient, with packings of the finest paper, which may now be obtained less than one thousandth of an inch in thickness. But in every instance these tools wear to some extent before reaching the other end, even if there is nothing left for the last cutter in the series to cut away. The farther end of the bore is therefore smaller than the other to an extent which is never less than one thousandth of an inch; but this difference is not considered sufficient to warrant the risk that would be incurred in proceeding from the other end a second time with a newly-adjusted instrument still untried. In dealing with muzzle-loading guns the difficulty is much increased in comparison with breech-loading, as the latter afford great facility of arrangement; and it is to breech-loading guns that the present paper chiefly refers.

In order to prepare for the last boring but one, the original bore of the innermost tube becomes the basis to work from, on the same plan as already described with reference to the previous preparation of this tube for building up the gun. It has lost its truth to some extent by the shrinking on of the exterior tubes, but that is recovered by future steps. A true bearing is then turned upon the exterior of the gun at both ends, and it is placed in bearings on a long saddle in a vertical machine. A boring bar with several sets of cutters is used, which works in bearings at both ends of the gun, and has upon it a block that follows the last set of cutting instruments. The bar revolves in fixed bearings, the gun having a slow motion upwards. There is usually about $\frac{3}{16}$ of an inch in the diameter to be cut out by this preliminary operation, and the aim is to continue the bore up to the required size, namely, $\frac{3}{1000}$ of an inch below the finished dimension, but this is seldom done; care is taken, however, that the bore is not above the size. It might be supposed that the turned bar and bored bearings would give a round hole, but this is not the case unless they are perfectly round themselves; hence these portions of the machine are looked upon as a foundation of truth, and are prepared as carefully as if intended for gauges. The boring bars, although made of steel like the gauges, are constantly wearing, and require vigilant attention to keep them up to truth. The hole from this boring is generally nearly straight, but never parallel; hence it is difficult to examine it with gauges, although no other mode of measurement is of any value in giving precise information on so delicate a point.

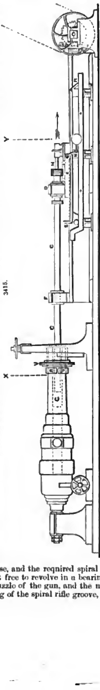
The next and last boring is done with the intention of making the hole parallel, but with no effort at straightness except what is derived from the bore itself as already made. The tool employed is a long broaching bar, shown in Fig. 3421, with six cutters A A arranged in two sets of three each, as shown enlarged in Figs. 3422, 3423. The first three cutters have all the work to do, the second set on entering being adjusted to the same diameter and intended only to scrape any of the surface that may be left from the first, which is not much, as there is seldom more than one thousandth of an inch altogether to be cut away. Both sets of cutters cut on the side rather than the front. The value of three cutters for steady cutting is well known; but it is also found that such an instrument is very apt to make a bad polygonal bore unless it copies a true circular form from something else. This true circular form, in addition to straightness of bore, is taken from the bore itself as already made. The transfer is effected by means of the bearing surfaces B B on the broaching block, Fig. 3422, which are long spiral surfaces made of gun-metal and filling the bore. In the earlier instruments it was found that straight bearing surfaces on the broaching block were liable to allow the roundness of the bore to wander into a polygonal shape; but by twisting the bearing surfaces into a spiral form round the block, as shown at B B in Fig. 3422, this liability has been prevented. An ordinary horizontal lathe is the most convenient for this operation, but it is found difficult to keep the bore sufficiently clear from the cuttings; hence the lathes are placed at a considerable inclination, to allow a stream of soapy water to flow through.

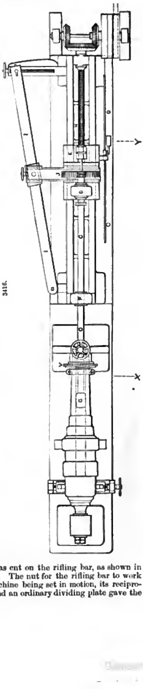
The bore is now within one thousandth of an inch of being parallel, but is never positively correct, though considered sufficiently so in the present stage of the manufacture. All the tool adjustments for these precise dimensions are performed with great strictness by a special department; still, with all the care that can be employed it is found extremely difficult to obtain at once the required conditions of correct size and roundness, with a straight and parallel bore. The gun thus bored, when examined and passed by the measuring department, is ready for the operation of rifling. Without this special department for measuring, the quality of the gun would speedily degenerate and tell unfavourably on the smooth cutting of the grooves in the rifling, since the rifling block is entirely dependent on the bore for its parallelism and steadiness.

The foregoing mode of boring applies to guns that are open at the breech; but in the case of muzzle-loading guns that are closed at the breech the approximation to a perfect bore is obtained by boring entirely from the muzzle and employing extreme care in opening with a slide-rest; and then by having nicely-fitted bearings behind the cutters so as to transfer the truth of the muzzle onwards, which is accomplished to a certain extent successfully, but not so perfectly as by the former arrangements. Much more skill in the workman is required to produce a perfect bore; indeed it is rare to find a bore which may be pronounced nearly perfect in the strict sense of the word; and any want of that high condition tells severely on the future operation of rifling, when the fitting of the rifling block in the bore is dependent on the parallelism of the bore for its steadiness and smoothness of cutting.

The manner of cutting the interior grooves for rifling the gun is independent of the different descriptions of rifling; and in any plan of rifling, with proper arrangements for transfer from copies, the most recondite descriptions of grooves can be formed inside the gun as easily as straight lines on the exterior.

In 1845, some guns being suddenly required to be rifled, an ordinary planing machine was extemporized for the purpose, and the required spiral was cut on the rifling bar, as shown in Figs. 3424, 3425, which was left free to revolve in a bearing. The nut for the rifling bar to work through was attached to the muzzle of the gun, and the machine being set in motion, its reciprocating action effected the cutting of the spiral rifle groove, and an ordinary dividing plate gave the

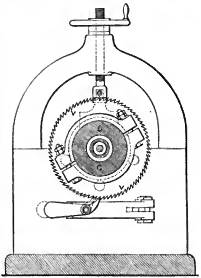

3415.


3416.

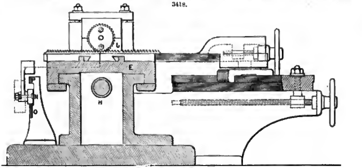
requisite number of grooves. Such a combination possessed all the elements for rifling guns with a simple spiral that was parallel at the sides and on the bottom; but in practice guns have to be rifled with a continually varying twist, with a varying width of groove, with sudden turns, with the shape of one side of the groove continually altering in form, and with many other peculiarities; and hence such simple arrangements will not suffice for their production, and other combinations have to be resorted to.

During the last few years an extraordinary amount of attention has been directed to the subject of rifled guns, and as most of the inventions have been carried out in the Royal Gun Factory (under the superintendence of John Anderson), it has been necessary to provide for executing any description of grooving without having recourse to an elaborate copy for each in the immediate instrument, which is expensive, and usually involves the loss of considerable time in getting the gun ready for trial. At the same time it may be stated that the simple square bar cut in a spiral or twisted form, as shown in Figs. 3424, 3425, when it can be employed, is the most perfect rifling instrument, because there can be no error in using it, which is not the case when the twist of the grooves is dependent on the adjustment of a machine that is ready to perform any description of grooving. In the construction of permanent rifling bars it is now found that a round bar with a spiral groove cut in it answers the purpose almost as well as the square bar cut into a spiral or twisted form, as shown in Figs. 3424, 3425, the spiral groove in the round bar and also the spiral twist in the square bar being both cut in an ordinary screw-cutting lathe. Such bars, however, cannot readily be applied where the spiral is of increasing pitch, where there are sudden curves, where the grooves shunt, or indeed for any groove which is not a true portion of a screw.

3417.



3418.



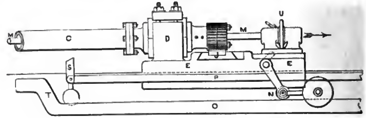
In a rifling machine, Figs. 3415, 3416, intended for irregular grooving it is necessary that there should be facilities for cutting any form of twisted groove, first as regards the sides of the spiral, and secondly, as regards the bottom of the groove; and the two requirements must be so combined that all the cutting may be done at the same time.

Such a machine is shown in Figs. 3415 to 3420, which represent the rifling machine employed in the Woolwich Gun Factory. Fig. 3415 is a general side elevation of the machine, and Fig. 3416 a general plan. Figs. 3417, 3418, are transverse sections to a larger scale, and Fig. 3419 an enlarged side elevation of the traversing saddle which carries the rifling bar. Fig. 3420 is a combined diagram illustrating the principal motions, the tangent bar I which gives the twisting motion to the rifling bar being here represented in the vertical plane, in order that it may be seen in combination with the copy bar O, which gives the feed motion to the cutter in the rifling head: the lengths are also shortened in some of the dimensions for convenience of illustration, but the side elevation and plan, Figs. 3415, 3416, show the correct dimensions and relative positions of the various portions of the machine.

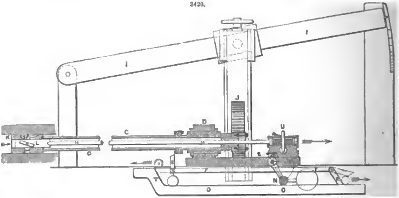
The rifling bar C, Figs. 3415 and 3420, is round and parallel, one end being held firmly in a bearing D on the traversing saddle E, with a number of collars to take the pull of the cutter;

while the other end is free to turn and slide in a stationary bearing F near the muzzle of the gun G. The longitudinal motion of the rifling bar may be given by any of the planing-machine motions; that by the screw H, Fig. 3416, is preferred on account of the smooth action which it affords. The twisting motion of the rifling bar is derived from the tangent bar I by means of the rack J sliding transversely on the traversing saddle E, and gearing into a pinion on the end of the rifling bar C, Figs. 3418, 3419. The tangent bar I can be set at any angle by means of the adjusting screw and graduated arc, or can be made of any shape within the limits that the machine is capable of following the quirks of the rifling. Hence to produce any description of twisting in the grooves of the gun it is only necessary to employ a tangent bar of suitable pattern for the purpose, which will be faithfully copied on the interior of the bore by means of the rack J tracing the pattern. In guns where there are several twists or alterations of form in a single groove it is sometimes necessary to have several differently-shaped tangent bars piled one on the top of the

3419.



3420.



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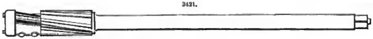

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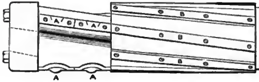
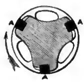
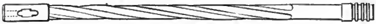


3423.



3424.



3425.

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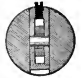
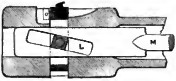
other, each of which is used in turn by adjusting the tracing rack J to the bar to be copied; and in this way any form, however recondite, can be accomplished as easily as a regular spiral.

In the greater number of rifled guns the depth of the grooves is uniform, but in others it is a varying surface at different positions of the bore; hence it is necessary to have the cutting instrument arranged so as to vary in depth as it proceeds along the gun. It is also of importance that the cutter should not rub on the gun as it returns, since the rubbing affects the maintenance of a fine cutting edge on the tool, and smoothness of cutting is an essential condition. It is therefore necessary that the cutting tool shall be in a slide-rest or holder in the head of the rifling bar, and capable of being drawn out or in transversely as required. For this purpose the rifling bar C is made hollow, and the tool holder in the rifling head K, Fig. 3420, is actuated by an inclined slot L in the internal feed-rod M, as shown in the enlarged sections of the rifling head, Figs. 3426, 3427. By working the feed-rod M longitudinally out or in, a radial motion is given to the cutting tool in either direction. The feed-rod M projects from the other end of the hollow rifling bar C, and its longitudinal movement is governed by the roller N which traces the copy bar O, Fig. 3420; the form of the copy bar O is thus transferred by the lever to the feed-rod M, and hence any indentations on the bar O are given to the bottom of the groove in the gun. To prevent the cutting edge of the tool from rubbing in its return, an upper rail P is provided, having a trap R and S to open and close at each end in order to allow the tracing roller N to pass. The drawings represent the machine in the forward traverse, in the act of cutting a groove in the gun, the arrows showing the direction of the motion. During this time the roller N is tracing the copy bar O; but on arriving at the end of the bar the roller lifts open the trap R, as shown dotted in Fig. 3420; and when it has passed the trap, the latter immediately falls and forms an incline for the roller to run up in its return course backwards and ride upon the upper rail P, thus pushing the feed-rod M inwards in the rifling bar C, and thereby withdrawing the cutting tool, which remains withdrawn during the whole of the return traverse of the machine. When the roller N reaches the other end, it finds the trap S open by means of the balance weight; but the roller folds the trap downwards, as shown dotted in Fig 3420, thus forming a bridge to enable it to pass over. The trap is then opened again by the balance weight, and on starting again in the forward motion the roller drops down the incline T at the commencement of the copy bar O, thus drawing out the feed-rod M and thereby advancing the cutter into its working position. The incline T gives the form to the entrance of the groove in the gun, and is generally of very definite shape. It will thus be seen that any description of feed-motion can be given to the cutting tool; and hence by means of the tangent bar I and the copy bar O any kind of rifling can be accomplished without difficulty. To illustrate the capability of the machinery, a specimen rifled tube has been made (shown in the International Exhibition) with grooves cut in four different ways, one of which is spiral and wavy, undulating on the bottom, and having the width of the groove formed with a progressive irregularity.

3426.

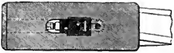


3427.

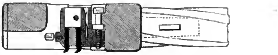


For the purpose of advancing the cutter and each traverse so as to obtain the additional depth required in the next cut, the outer end of the feed-rod M has a screw and hand-wheel U upon it, Fig. 3420, by which the cutter is set up to cut deeper in each successive traverse, until the groove is finished to the required depth. The hand-wheel also affords the means of taking up the wear of the cutter, so that all the grooves are finished to exactly the same depth. When one groove is completed, the gun is turned forwards through the required arc by means of the ratchet-wheel V upon the muzzle, Fig. 3417, which serves as a dividing plate, being made with the same number of teeth as there are to be grooves in the bore of the gun.

3428.



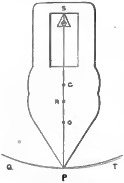
3429.



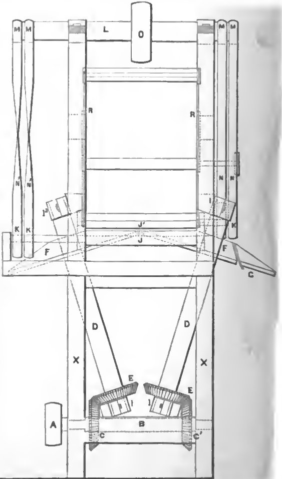
Experiments have recently been made with another kind of cutting instrument, by which the whole of the grooves are made at one time by means of a circular rifling head carrying as many cutters as there are grooves to be made. A series of these rifling heads are used in succession, following one behind another on the same bar, each one cutting the groove a little deeper than the preceding one, and by pulling through ten or twelve of them the grooving is effected. This kind of instrument is applicable only to breech-loaders, but so far as economy is concerned it is the most expeditious of all methods. In some of the rifling tools made on the former plan of withdrawing the cutters in returning, eight cutters have been used; but it is doubtful whether they are more economical than a smaller number, as time is lost in obtaining perfect adjustment with so many cutters working to one thousandth of an inch. Where no variation is required in the depth of the grooves, a rifling head with fixed cutters can be used, as shown in Figs. 3428, 3429. The cutters are here fixed in a block rocking upon a centre pin in the rifling head, to allow them to clear in the return traverse, as in a planing machine; they are set up after each traverse by an adjusting screw in the rifling head, advancing the block in which the cutters are fixed. This rifling head is for cutting the grooves in muzzle-loading guns, the cutters being set to cut inwards from the muzzle towards the breech as the rifling head is pushed down the gun, instead of in the contrary direction as in the rifling head previously described and shown in Figs. 3426, 3427.

The copying principle is also used in drilling the various holes for the sights and other parts upon the outside of the guns. In a gun which is intended to hit a target at 2000 or 3000 yds. distance, the value of the thickness of a line in half the length of the gun is important; and as all the Armstrong guns are made so that the several parts interchange, absolute precision in the positions of the several holes is essential. Most of the holes have to be drilled on the side of the gun, where the difficulty of entering correctly is greatly increased on account of the surface being oblique to the direction of the holes; so that the drill requires to be guided very steadily, and the ordinary plan of dividing off the holes and the use of a centre punch are altogether inadmissible. A cast-iron saddle is therefore made to fit upon the gun and also upon the trunnions, being cast in halves, so that the whole of that part of the gun in which the holes have to be made is enveloped in it. The saddle is correctly made with copy holes lined with steel, the several holes being of the required dimensions of the holes to be made in the gun. Cylindrical drills are employed, which, fitting the holes in the copy, give the utmost accuracy to the sight-holes without any effort.

3430.



3431.



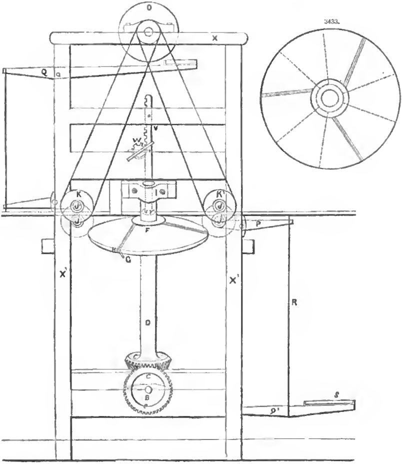
GYRATION. Fr., *Mouvement giratoire*; Ger., *Kreisförmige Bewegung*; Ital., *Girazione*; Span., *Rotacion*.

The centre of gyration is that point in which, if all the matter contained in a revolving system were collected, the same *angular velocity* will be generated in the same time by a given force acting at any place as would be generated by the same force acting similarly in the body or system itself.

The distance of the centre of gyration from the point of suspension, or axis of motion, is a mean proportional between the distances of the centres of oscillation and gravity, from the same point or axis. If S, Fig. 3430, be the point of suspension of any regular or irregular body P S; G the place of the *centre of gravity*; O that of the centre of oscillation; and R that of the centre of gyration; then $RS = \sqrt{SO \times SG}$; hence, $SO \times SG$ = a constant quantity for the same body and the same plane of vibration S Q T. If $SG = 25$, and $SO = 36$ units of length, then $SR = \sqrt{25 \times 36} = 30$.

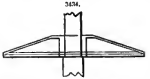
Ira Gay's Conical-Plate Planing Machine.—In this machine the centre of the cutting edge coincides with the centre of gyration of the revolving cutter-holder. Ira Gay was an experienced mechanical engineer; he was born in Dunstable, in the county of Hillsborough, New Hampshire, U.S. His machine, Figs. 3431 to 3435, for planing boards, plank, and other articles, is not of a complicated nature. Fig. 3431 is a front view of the machine; Fig. 3432, a side view; Fig. 3433, the plane-stock; Fig. 3434, a section through the centre of the plane-stock; and

3432.



3433.

3434.



3435.

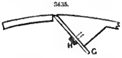
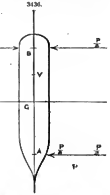


Fig. 3435, a section of the plane-stock cut across so as to show the plane-iron and the manner of fixing it to the stock. A is the main pulley to which the power for driving the planes is applied by means of a belt. B, the main shaft on which the driving wheels C C are fastened. D D, upright shafts inclining a little from a perpendicular position. E E, wheels attached to the upright shaft D, and driven by the wheels C C. F F the plane-stocks attached to the shaft D D.

The face of the plane-stock may be levelled to suit the views of the operator, but must be levelled enough to throw off the shavings freely; more than this tends to render the surface planed uneven. An angle of about 5 degrees from a right angle to the shaft is a very good inclination. The plane-iron is shown at G, Fig. 3435, which also shows the manner of fastening it to the stock by means of the screw H. J J are the receiving and delivering rolls driven by the pulley K. T T, boxes for the upright shafts to revolve in. At the top of the machine is the shaft L for the purpose of driving the receiving and delivering rolls, upon the ends of which are pulleys M M, corresponding with those on the rolls over which pass the belts N N. O, the pulley for communicating motion to the shaft L. P P are levers attached to the rolls and made to pass them together while the boards are passing through the rolls; these levers are assisted by other levers Q Q, connected by the rod R R, and weighted as seen at S S. T is a board passing through the machine and confined down to the plane by means of two small rolls U V, which are adjusted to their proper place by means of the rack V and pinion W. X is the frame of the machine. The mode of using the machine is simply to insert the end of the board between the receiving rolls, after which the board is carried through the machine by means of the rollers, and planed in its passage.

Centre of Spontaneous Rotation.—No matter what the nature of an impulsive force may be, or how that force is applied to a body at liberty to move in any direction, the whole force, when not applied to the centre of gravity, is employed to turn the body, and at the same time the whole force is employed to move the centre of gravity in the direction of such force. To illustrate this important proposition, let A B, Fig. 3436, be a body placed anyhow, at liberty to move in any way. The force P, or two forces, each equal to ½ P, is exerted at the point A; P has the power to turn that body, and to drive on the centre of gravity. We have then to consider the centre of oscillation, the centre of percussion, the *centre of spontaneous rotation*; we have nothing to do with the centre of gravity once the force acts upon a body and attempts to move it. If we apply two new opposing forces each equal to ½ P at the same distance as P from the centre of gravity G, they would balance each other, and would not interfere with either the progressive or the turning motion. But we shall now consider another arrangement of these forces; two ½ P's will drive on the centre of gravity; the other two ½ P's will turn the body round with a force equal to P. ½ P at A and ½ P at B turn the body round, and ½ P at B and ½ P at A have a tendency to give a progressive motion to G, consequently the force P acting at A loses none of its effect to turn the body, nor any of its driving effect. What will happen;—The point A will advance by two forces, the force of turning and the force of percussion, while the point B will advance by one force = $\frac{P}{2}$, and will turn in an opposite direction; the result will be the difference, so that the point B will recede while the point A will advance. Therefore this body will turn round a point V between G and B, which is called the centre of *spontaneous rotation*. See ANGULAR MOTION. GRAVITY. OSCILLATION. PERCUSSION.

3436.



HACKLE OR HECKLE. FR., *Séran, sérin, séranzoir*; GER., *Hechel*; ITAL., *Pettine*; SPAN., *Rastrillo*.

See FLAX MACHINERY, p. 1498.

HAMMER. FR., *Marteau*; GER., *Hammer*; ITAL., *Martello*; SPAN., *Martillo*.

See HAND-TOOLS.

HAND-GEAR. FR., *Levier à main de distribution*; GER., *Handsteuerungshebel*; ITAL., *Messa in moto*; SPAN., *Palanca de trasmision de movimiento*.

The contrivances in a steam-engine for working the valves by hand; the starting gear.

HAND-PUMP. FR., *Pomp à main*; GER., *Handpumpe*; ITAL., *Tromba a mano*; SPAN., *Bomba de mano*.

A pump situated at the side of the fire-box in a locomotive, and worked by means of a lever when the engine is standing with steam up.

HAND-SAW. FR., *Scie à main*; GER., *Handsäge*; ITAL., *Segone*; SPAN., *Serrucho*.

See HAND-TOOLS.

HAND-TOOLS. FR., *Outils à main*; GER., *Handwerkzeuge*; ITAL., *Strumenti da mano*; SPAN., *Herramientas de mano*.

Hand and Foot Lathes.—John Anderson, the Superintendent of the Woolwich Machine Shops, in the P. I. M. E., 1862, observes, "In looking back to the early days of the turning lathe, before the introduction of the transfer principle in the sliding rest, it is interesting to observe that even then the lathe was a perfect instrument so far as it was a copying machine; those common lathes that were made with a perfectly round spindle-neck, if any such existed, would yield a round figure in the article under operation, providing that the cutting instrument was held steadily. And even in a still higher degree was correct workmanship attained in the old-fashioned dead-centre lathes; if the centre holes in the article to be turned were formed with moderate care, and the article held steadily between the centres, then the surface developed by the cutting instrument when firmly held would be as perfect a circle as one described by a pair of compasses."

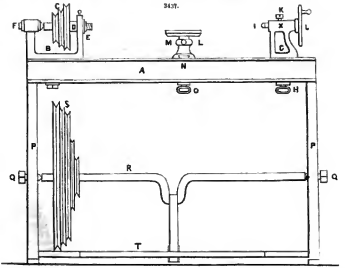
With such apparatus, however, the chances of error were numerous, arising principally from the spindle-necks not being perfectly round; for even in the case of modern lathes a perfect spindle-neck is more rarely obtained than is generally supposed, as a close examination will show, the polygonal form being much more predominant than the true circle. There are lathes, even among those of the most recent make, which have only to be handled gently to show their condition in this respect. Until recently such approximations to roundness were sufficient; but the extensive introduction of *accurate gauges* into workshops has, besides teaching the importance of precise dimensions, made engineers familiar with true circles. Hence there is now a much greater appreciation of positive truth of workmanship, and positive truths are always important; and in well-conducted workshops there is a constant striving after that condition and a gradual closing up of every avenue whereby error can creep in.

Such extreme accuracy is sometimes thought to be more costly than a less careful system; but practical men, like Anderson, have arrived at a contrary opinion, and are convinced that while extreme accuracy may be more expensive at the outset, especially from the want of workmen competent to carry it out, yet with a little perseverance the advantage arising from it will be clearly perceived, and the apparently inordinate cost will shortly be brought below that of less perfect arrangements. Many articles after being carefully turned and planed have to undergo a long course of filing and scraping before they are brought to the required quality of surface; whereas, if a small fraction of this outlay were spent in making the copy in the lathe spindle or the copy in the plane perfect as patterns, the great expense of subsequent fitting would be avoided. Many examples bearing on this point could be given were it required; an illustration may be named that came under Anderson's experience in the manufacture of guns at Woolwich Gun Factory. Certain rings about 1 ft. in diameter had to be fitted on corresponding cylinders, and were required to be perfectly easy to move, yet without shake, as any looseness in the fit rendered them useless; they had therefore to fit approximately like the Whitworth gauges. Several good new lathes were tried in vain; endless scraping and grinding had to be resorted to. Anderson was convinced that if the source of roundness were positively round, the result ought not to be out of truth. Measures were accordingly adopted to obtain perfection of roundness and steadiness in the lathe, at little more than the cost of fitting one of the rings; and the subsequent cost of the rings was thereby reduced from the value of nearly three days' work to less than an hour's. The lathe spindle became a true copy, the sliding rest a correct medium of transfer, and the combination of the two yielded the required truth and roundness. A similar case occurred in the manufacture of a number of large fire-cocks: the sockets and plugs were carefully turned, but they would not resist the water pressure without a great deal of scraping and grinding, until the lathe spindle was positively brought to perfect roundness, when the turning alone made them fit with scarcely any grinding. The lathe is a copying machine, and just as its bearing surfaces are so is the work produced.

The apparatus generally employed by wood and ivory turners is termed a foot-lathe, on account of its being driven by the foot in the same manner as the common grinder's wheel; some are constructed partly in metal and partly in wood, but those made entirely of metal are far superior to these, and are of the following construction:—

A, Fig. 3437, is the bed of the lathe, upon which two supports, called poppet-heads, rest: the surfaces of contact vary in form, in some beds both are flat, in others both angular, and in others one angular and the other flat.

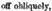
3437.



By many the angular or V beds are preferred, from the idea that the heads are more likely to retain their proper position than when resting on plane surfaces; but the latter, when accurately planed and fitted, are quite as worthy of relience, and far more convenient than the angular-bedded lathes.

B represents the head to which the chucks are attached, and by means of which the power requisite for rotating the work is applied. This poppet-head consists of a strong frame of cast iron F B E; in the standard E is fixed a hard conical bearing, in which one end of the mandrel D revolves, and by which it is supported, the other end resting against the hard conical point of a screw placed in a nut at F; by means of this screw the mandrel is kept tight up to its bearings, any tendency of the screw to shift being prevented by one or two nuts upon it, which are screwed up tight against the standard F.

At the bottom of the head is a solid projection, which is made to fit the opening between the sides of the lathe-bed, and by which the parallelism of the lathe-bed and mandrel is maintained. The head is firmly fixed in its position by a bolt, which draws a strip of metal up tight against the bottom of the lathe-bed. A number of groove pulleys G are attached to the mandrel, one of which is connected with the pulleys S on the driving shaft R by means of a cord of catgut or gutta-percha, although in a case of necessity a sash-line may be made to answer the purpose. The catgut is, however, the most satisfactory, on account of its great durability. The plan usually adopted for joining the ends is to screw on hooks and eyes; the end of the gut is slightly tapered and damped, so that the hooks and eyes may squeeze the gut into a screw rather than cutting it, by which latter the band would be much weakened.

It must not be used until the gut is dry and hard. Gutta-percha bands are united by heat, the ends being cut off obliquely, thus, , and gently heated by means of a hot piece of smooth clean iron, until soft, when they are firmly pressed together, and kept in that position until cold. This, of course, necessitates the stoppage of the lathe for some time, besides shortening the band every time it is united.

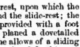
When the work is too long to be supported entirely by one end, a second poppet-head is required, which is of the form shown at C; this head is accurately fitted to the lathe-bed, and can slide upon it to allow of adjustment to the length of the work; it is fitted with a clamping screw H to fix it when in position, also a conical point I, called a centre, which is movable through a small space by the handle J, to allow the removal of the work from the lathe without shifting the poppet-head. The mandrel carrying the centre is fixed after adjustment by the capstan-headed screw K.

The next part of the apparatus to which our attention is called is the rest, upon which the operator supports the turning tool. There are two kinds, the common rest and the slide-rest; the former is that represented in our figure. M L is a short hollow column, provided with a foot sufficiently long to reach across the lathe-bed; in the bottom of the foot is planed a dovetailed groove N, which retains the head of a clamping screw O, but at the same time allows of a sliding motion when not clamped. From this it is evident that the rest can be placed and fixed in any position.

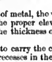
Within the hollow column is a cylindrical rod, which carries a straight strip of metal, the whole being raised or lowered by sliding the rod vertically in the column; when the proper elevation has been attained, the rest is fixed by a screw working in a thread cut in the thickness of the column.

The lathe-bed is supported on standards or frames P P, which also serve to carry the crank-shaft R by means of two conical-pointed screws Q Q, which enter countersunk recesses in the ends of the shaft. The shaft is made with one or two cranks, or throws, according to its length. This shaft is also fitted with grooved driving pulleys S, made of various diameters, in order to obtain any speed which may be required. The pressure imparted to the treadle T is communicated to the crank by a link with a hook at each end, or by a chain; some turners preferring the former, and others the latter.

3438.



3439.



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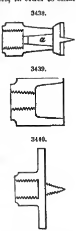


We now proceed to consider the means by which the work is held in the lathe and caused to rotate with the mandrel.

Fig. 3438 represents the fork, prong, or strut-chuck, so called from the steel fork or prong *a*, which is fitted into the square socket of the chuck; this chuck is used for long pieces, the point supporting one end of the work, the other being supported by the back centre. The chisel edges on each side of the point take hold of the work and ensure its rotation. The fork being fitted into a square recess in the chuck may be replaced by drills, &c., or small pieces of wood or ivory to be turned. It is usually made of metal, and attached to the mandrel by an internal screw corresponding to that on the nose of the mandrel.

Fig. 3439 represents the hollow or cup-chuck; it is used for holding short pieces, or pieces that are to be turned out hollow. Its inside is turned slightly conical, so that the work may be driven tightly into it.

This chuck is usually made of boxwood, sometimes strengthened by a metal ring round the mouth of it; but this is scarcely necessary, as a very slight blow is sufficient to fix the work if it has previously been reduced to a form nearly approaching the circular by the chisel, paring knife, or other hand-tools.

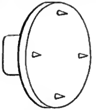
Fig. 3440 represents the face-plate or facing chuck; it may be made of iron or other suitable material.

This chuck is turned flat and perfectly true, and is fitted at its centre with a conical screw to hold objects to be turned on the face. This chuck can only be used when the hole made in the work is not objectionable, or can be plugged up. The screw should only be very slightly taper, otherwise the work will not hold when reversed.

Fig. 3441, a chuck for flat work, where a hole in the centre would be detrimental. It is a face-plate with three or more small spikes projecting from its surface to penetrate the material to be wrought, which is held against it by the back centre.

A plane face-plate is used where the work cannot be conveniently fixed to either of the two foregoing, as in the case of thin pieces of horn, tortoiseshell, and so on. The work is attached by means of glue, or of jewellers' or turners' cement.

3441.



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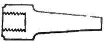

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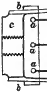


Fig. 3442 represents the arbor-chuck, usually made of brass. It is used for holding small hollow works or rings.

For very small work, Fig. 3438 is useful for holding the arbors in the place of a strut *a*.

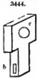
Fig. 3443 represents a spring-chuck which is used for holding very slight work that requires to be hollowed out.

It is turned conical externally, the apex of the cone being to the left. A few holes *a a* are drilled through the chuck near its base and at equal distances from each other. From these holes saw kerfs or slits are cut longitudinally to the front of the chuck, which allow the chuck to expand slightly to take a firm hold of the work, and when the work has been forced into the chuck, the grip is rendered still more firm by drawing a strong ring towards the front of the chuck.

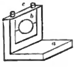
These chucks are sometimes made of wood, but those of metal are much neater and more convenient; they may be made of a piece of brass tube firmly driven on a wooden block.

A similar chuck is used for holding hollow work, but instead of being provided with an external ring, it is fitted with a short solid plug, which is forced forwards after the chuck has been inserted into the work. When long and slender pieces have to be turned, an extra poppet or a support is required to keep the work from shaking, or chattering, as it is termed. It is generally made of wood, and is formed similar to Fig. 3444. It consists of a head, in which is bored a hole *c* of the proper diameter, and a tail-piece fitted to the lathe-bed and sufficiently long to receive an aperture *b*, through which a wedge may be passed to hold it down firmly upon the lathe-bed.

3444.

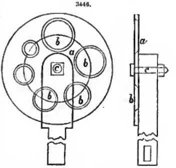


3445.



Another and more convenient form of support is shown at Fig. 3445; *a* is a cast-iron frame, having a foot fitted to the lathe-bed and furnished with a bolt and nut by which it is firmly bolted down to the lathe-bed; *b* is a block of wood fitted into the frame, where it is secured by the cross-bar *c*. An aperture of the required diameter is now bored in the block; it is then taken out of the frame and sawed in half, so as to form a top and bottom bearing; *d* shows a section of the frame; any other form of groove may be used, but we have selected the **V** on account of the ease with which the blocks may be fitted to them. One great advantage of the latter apparatus is, that the two bearings may be brought together when the hole is worn. When a slide-rest is used, this additional support should be attached to it; it will then keep close to that part of the work on which the tool is acting, by which a more satisfactory piece of work is turned out, and the trouble of shifting the poppet avoided. The application of a little grease to these bearings will sometimes be found beneficial.

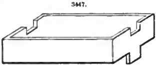
3446.



An apparatus called a boring collar, somewhat similar to that just described, is used for supporting the ends of pieces of which the ends are to be bored, and which are too long to be held by the cup-chuck alone. It consists of a plate similar to a face-chuck, Fig. 3446, through which a number of conical holes are bored, whose centres are equidistant from the centre of the plate, so that when the latter is turned on its axis any hole can be brought exactly in a line with the two centres. The plate may be attached to a standard similar to either of the foregoing.

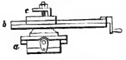
It may sometimes occur that the work to be turned, as a wheel, the foot of a stand, and so on, may be rather too large for the lathe; in this case it is convenient to have frames truly planed and fitted. Such a frame is shown at Fig. 3447. It is made of cast iron, the top being fitted to the bottom of the poppet, and the bottom being fitted to the lathe-bed, care being taken that the mandrel is retained parallel to the lathe-bed. The rest may be blocked up in a similar manner, or a temporary rest may be made of a piece of bar-iron bent to a suitable form.

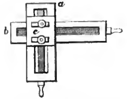
3447.



In some cases it will be convenient to have a self-acting slide-rest, as for turning large screws, spirals, and so on. The slide-rest is shown in Figs. 3448, 3449. Fig. 3448 is an elevation, and Fig. 3449 is a plan. *a* is a slide which fits the lathe-bed very accurately, but will yet slide freely upon it, and in a direction exactly parallel to the axis of the object to be turned. *b* is another slide fitted to the lower one and sliding upon it in a direction at right angles to the lathe-bed. It is worked by a screw attached to the lower slide, which gears into a nut fixed to the bottom of the slide *b*. Upon the slide *b* is fitted a small slide *c*, upon which the turning tool is fixed by means of a clamp. This slide is moved in a direction parallel to the lathe-bed by means of a screw attached to the slide *b*, gearing in a similar manner to that in the slide *a*. The whole slide may be moved along the bed either by hand or by means of a screw running along the side of the bed and gearing into a nut made in two halves, so that it may be thrown into or out of gear by closing or opening the nut. The use of this screw, which is called the leading screw, requires a different form of fixed poppet-head, and constitutes what is called a screw-cutting lathe, on account of its suitability to that process.

3448.





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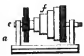

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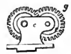

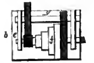

3452.

The poppet-head generally fitted to self-acting lathes is represented in Figs. 3450 to 3452. *a* is a side elevation, *b* a plan, and *c* a front elevation. This head is fitted with speed pulleys *f*, which may be made fast to the mandrel, so as to drive it direct or loosened, and geared by a tooth-wheel with the shaft *g*, which again gears into the mandrel, which is supported in bearings at each end. The wheels on the shaft *g* are thrown out of gear with those on the mandrel by sliding the shaft endwise in its bearings. It is retained in or out of gear by a pin passing into the bearing, which rests against a groove turned on the shaft *g*. On the end *e* of the mandrel a toothed wheel is slid and retained there by a nut. This wheel may act directly upon another placed on the end of the leading screw, or may be connected with it by means of one or two intermediate wheels, according to the speed required and the direction of the intended screw.

It is evident from this arrangement that any ratio between the speeds of the mandrel and leading screw may be obtained either for cylindrical turning or screw-cutting.

Fig. 3453 is a very complete double-gear foot-lathe, with planed bed, standards, anti-friction treadle, with chain, crank, and driving wheel, hand-rest, face-plate, drill-chuck, and two centres.

Fig. 3454 is of a single-gear foot-lathe, with planed bed, standards, anti-friction treadle, with chain, crank, and driving wheel, hand-rest, face-plate, drill-chuck, and two centres.

Fig. 3455 is of an amateur's lathe, with fast and loose headstock, hand-rest, and metal table.

Fig. 3456 is of a compound slide-rest; another arrangement of compound slide-rest is shown in Fig. 3457. Figs. 3437 to 3452 are employed to illustrate principles; Figs. 3453 to 3457 are not fancy sketches, but of machines manufactured in the highest style by J. and H. Gwynne, of Hammersmith, and by William Muir and Co., of Manchester.

Figs. 3458, 3459, are two views of Benjamin Merritt's machine for boring angular holes. B is the frame of the machine, D is a driving shaft, E E bevel-gear for communicating motion to the operating shaft. The novelty of Merritt's boring machine consists in attaching around the operating shaft of an ordinary boring machine a cam H, on the under-side of which is a path of the form of the hole to be bored. In this path runs a truck attached to a box having a rack and pinion which give motion to the hollow main shaft as well as to an inside shaft. To the bottom of

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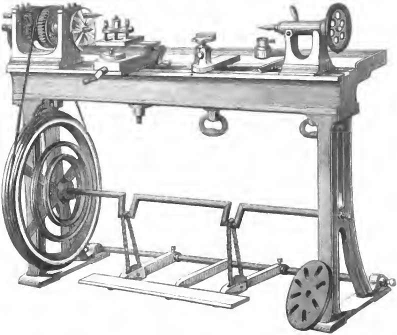

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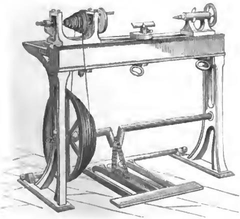
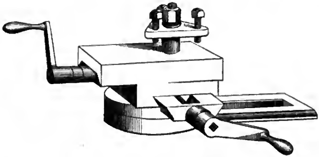


3455.

the main shaft circular cutters *a* are attached, and a tug screw to draw the auger into the work. Inside the circular cutters and attached to the inside shaft is a pinion which gears into two racks,

3457.



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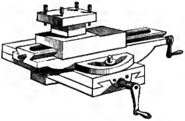

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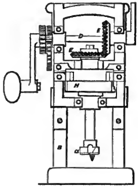

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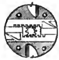


Fig. 3459, having cutters on opposite sides so arranged that when the main shaft rotates, the inner shaft, by the operation of the travelling truck in the cam, turns one-half way round, causing the cutters gradually to project from the line of the circular hole to the angle, as at J J; the operation of the two cutters being simultaneous, the angles are thus cut to form the angular hole.

Dividing Machines are for marking the divisions upon mathematical and other instruments, common rules and scales, glass tubes, &c.; they are of two kinds, designed respectively to divide the straight line and the circle.

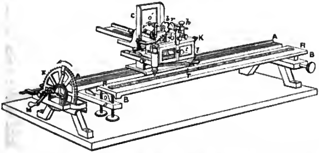
Machines for Dividing the Straight Line.—The principal part of these machines consists of a screw of from 15 to 24 in. in length, the pitch of which is some exact measure of an inch, or some other chosen unit; in French instruments the pitch is always equal to 1 millimètre. It is obvious that the accuracy of this screw determines the merit of the machine.

The screw is placed horizontally through a fixed shoulder, and works into a female screw, to which the dividing instruments are attached; the frame C, Fig. 3460, bearing these instruments, slides upon guides parallel to the axis of the screw. It will be seen that when the screw is turned in the required direction by means of a crank, the female screw advances a linear quantity proportional to the angular quantity turned by the screw. The part C is furnished with a *tracer* to mark the divisions; when the divisions have to be marked upon metal, the tracer or graver is of steel, but in the case of a glass tube a diamond is required. The piece to be divided is placed parallel to the screw upon a fixed table, and at a convenient distance. The graver may be raised by turning it about an axis parallel to the screw, during the time the latter is in motion; when the screw has revolved sufficiently, the graver is pulled down upon the piece to be divided, and a motion perpendicular to the axis of the screw is imparted to it by pressing it gently upon the piece in order to mark the division; the part to which the graver is affixed being arranged to move perpendicularly.

The general arrangements which we have described above are those which are adopted for all kinds of engines for dividing the straight line. But these kinds differ widely from each other with respect to accessory means employed for regulating the distance and the length of the division-marks. As we cannot describe every modification of engine, we will select one which seems to be contrived in the most rational manner.

Fig. 3460 represents the machine used by M. Salleron, whose instruments are justly esteemed throughout France for their accuracy. A A is a metal slab upon which the part C slides. The screw runs down the middle of this slab, and is turned by the crank M. B B is the plane table, also of metal, upon which the piece R R to be divided is placed. This table turns about the point a, so that by means of the thumb-screw the piece may be brought exactly parallel to the motive screw. The graver T may be slightly raised by turning about the axis $l m$; at the same time, the part $i k l m$ may turn about the axis $i k$. In this way the graver may be brought into contact with the piece to be divided at the farthest point its construction will allow; then pressing the graver gently upon the piece, the part $i k l m$ returns of itself to its original position, and the graver marks the division.

3460.

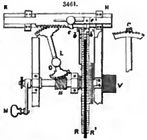


The motion of the graver is regulated by the following arrangements;—To the part $i k l m$ are fixed two vertical pieces o and h. Parallel to the piece o is another vertical piece turning about its lower end; this piece is not shown in the figure, but the wheel b which it bears on its upper end is there represented, as well as the little plane d with which it is provided laterally. This third piece is jointed to the frame by means of the horizontal piece t. It follows that when the graver is brought forward by turning the frame $i k l m$ about $i k$, the third piece turns about its lower end, and its upper end is thrown forwards, either by the plane d meeting the end of a fixed screw v, or by the wheel b coming in contact with the end of a screw o working in the piece fixed to the frame. When, on the contrary, the frame is brought back towards its position when at rest, the third piece to which we have already alluded, turns in the contrary direction about its lower end, and its upper end is thrown backwards, either by the plane d meeting the end of a fixed screw v' or by the wheel b coming in contact with the end of the screw o'. Let us suppose, in the first place, that we have to trace a series of divisions of equal length; the distance of the screws v and v' is regulated so that the stroke of the graver may be of the required length, and the screws o and o' are withdrawn, so that the wheel b may not come in contact with them. The plane d strikes, in this case, alternately against the screws v and v'; the excursions of the frame $i k l m$ are thus regulated in a constant manner, and the graver traces divisions of equal length. Suppose now it is required to trace divisions of unequal length, a longer one for every fifth, for example. The excursions of the frame will no longer be regulated by the plane d, because the screws v and v' will have been sufficiently withdrawn; in this case they will be regulated by the wheel b. This wheel is provided with notches. When the portion of its circumference between two notches comes in contact with the screws o and o', the excursion of the graver is small and it marks a small division; but if the screws o and o' enter a notch, the excursion of the graver is greater and it marks a longer division.

To regulate these long and short divisions, there is upon the axis of the wheel b a small ratchet-wheel r, which is furnished with it. A click at the end of the piece h works into the teeth of this ratchet. When the graver is brought forward, the end h is brought back, the click presses upon the ratchet and turns the wheel b; when the graver returns to its place, the click escapes from the teeth of the ratchet without turning it. It is evident that at each division traced, the wheel b turns by a certain quantity, and this quantity is regulated in such a way that at each fifth division, for example, the wheel b presents one of its notches to the screws o and o', which causes a longer division to be marked. A microscope at m enables the operator to see whether or not the divisions are marked regularly. Various means are provided to ensure to the motion of the graver a direction exactly perpendicular to the axis of the motive screw.

Let us now examine the mechanism for regulating the interval of the divisions. The wheel E upon the axis of the screw is divided into 100 parts; hence when it turns by n divisions, the screw advances by n hundredths of a millimètre. By means of a system of gearing we may turn the wheel E by the crank M and observe the number of divisions of this wheel which pass a fixed point. But in order to render the operation independent of the attention of the operator, an arrangement has been devised for regulating the interval somewhat automatically, thus avoiding a chance of error. This arrangement is represented in plane by Fig. 3461. The axle of the crank M is independent of the screw V. Upon this axle is fixed a ratchet-wheel R having 100 teeth. Opposite and upon the axis of the screw is fixed a similar wheel R′. The first is provided with a click c (represented apart) which works into the teeth of the second. If the crank is turned in the direction of the arrow in Fig. 3460, a direction which we will call direct, the click of the wheel R presses against the teeth of the wheel R′, and the crank thus turns the screw; but if the crank is turned in the direction contrary to that of the arrow, a direction which we will call inverse, the click slides over the teeth of the wheel R′ without turning it. The screw, therefore, turns only when the crank turns in the direct direction. The wheel R bears, opposite its 100 teeth, 100 equal divisions; opposite the *zero* of these divisions is fixed a stop *b*. A second similar stop *b′* is affixed to the end of an index placed between the two wheels upon the axis of the crank. By varying the position of the index, we may easily regulate the angular distance which separates the two stops. These stops meet two projecting pieces *e* and *e′* upon a rule K H moving between guides in the direction of its length. When the crank turns in the direct direction, the motion continues until the stop *b* meets the projection *e*, placed in its way; when the rotation takes place in the inverse direction, the motion continues until the stop *b′* meets the projecting piece *e′*. It is evident that the motive screw can advance only by the quantity corresponding to the angular space of the two stops, and that by an alternating motion, limited by the projecting pieces themselves, the operator moves the screw forward by rigorously equal quantities regulated beforehand. If, for example, it be required to move the screw forward half a millimètre at a time, we have only to place the index so that the angular space which separates the stops shall be exactly 180°. The plane of the upper face of one of the projections being supposed to coincide exactly with the lower face of the other, in order not to be obliged to consider the thickness of the projections.

3461.



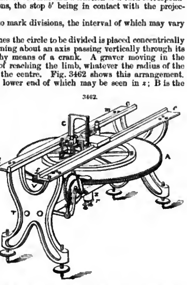
This arrangement is sufficient to ensure the equality of the spaces which separate the divisions whenever this space does not exceed 1 millimètre. But if the interval is to exceed 1 millimètre a special arrangement is required; this arrangement is the following;—

Upon the axle of the crank is an endless screw *u*, working into the end of a lever L, which turns about an axis O. The other end of this lever works into a straight rack upon the rule K H. Consequently the motion of the crank drives the rule backwards or forwards in the direction of its length. All that is required, therefore, is to regulate the interval of the projections so that the stop *b* may meet the projection *e* at the end of a number of turns and a fraction of a turn corresponding to the space which is to separate the divisions, the stop *b′* being in contact with the projection *e′* at the beginning of the motion.

By means of these arrangements we are able to mark divisions, the interval of which may vary from $\frac{1}{100}$ of a millimètre to several millimètres.

Machines for Dividing Circles.—In these machines the circle to be divided is placed concentrically upon a horizontal plateau or table, capable of turning about an axis passing vertically through its centre, and put in motion by a tangent screw by means of a crank. A graver moving in the direction of the diameter, in order to be capable of reaching the limb, whatever the radius of the circle may be, traces divisions directed towards the centre. Fig. 3462 shows this arrangement. A is the table turning about a vertical axis, the lower end of which may be seen in *z*; B is the circle to be divided, placed concentrically to the table; *c d* and *e f* are guides parallel to a diameter of the table, and upon which the part C, similar to that of Fig. 3460, slides, carrying a graver which moves in the direction of a diameter; M is the crank which turns the tangent screw V, which screw imparts motion to the table. This screw is furnished with a contrivance for regulating the length of the intervals similar to that which we have described above. By means of this contrivance we regulate the quantity by which the tangent screw is to turn, and consequently the angular quantity by which the table A is to turn for each of the divisions to be traced. This table has usually 720 teeth, each one of which, consequently, answers to half a degree. Its axis is a steel frustum of a cone resting upon a spring in a bronze socket fixed to the support T.

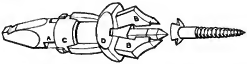
3462.



The chief difficulty of the operation consists in properly centring the circle to be divided. To do this, it is first fixed upon the table with wax, and the distance from every point in the circumference of the circle to the centre of the table carefully measured. When this distance is the same in all points, the circle is fixed with a mixture of wax and resin, and the operation of dividing the limb proceeded with. The operation of centring is a delicate one, but it is indispensable, especially when it is required to divide the limb of an instrument used for astronomical purposes.

Improved Wood Screw and Driver.—The slotted head of the common wood screw is frequently split when much force is required to seat it or to remove it, and every mechanic has been annoyed by the slipping off of the screw-driver blade from the head of the screw. To provide a remedy for these objections is the object of P. N. Jacobus, the inventor of the screw and driver shown in Figs. 3463, 3464. The screw-head has three V-shaped notches cut equidistant in the edge, instead of the single-cross slot. The screw-driver, seen in perspective in Fig. 3463, has three corresponding jaws which by a simple arrangement automatically open and close upon the screw-head, Fig. 3464.

3463.



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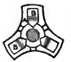
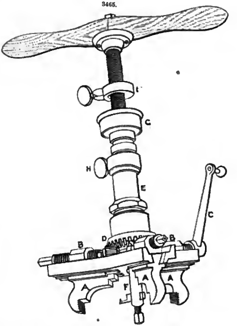


The stock A is intended to fit into a bit-stock, and is hollow for the larger part of its length, and has three longitudinal slots in which slide the jaws B, all moved simultaneously by a sliding ring C, with which they engage. They are opened and closed by means of the incline of their forward portion sliding through corresponding apertures in the collar end of the implement, designated by D in Fig. 3463.

When held in an upright position, the jaws down, the combined weight of jaws and ring causes them to fall, and the points of the jaws open sufficiently to receive the head of an ordinary screw. Now, if pressure is exerted, the stock is forced down and the jaws compressed, griping the screw-head with an energy proportioned to the force exerted; the harder the pressure the greater the tenacity of the grip. The edges of the jaw-points, when they are seated on the screw-head, project sufficiently to cut a countersink to seat the head, preventing the necessity of using a separate tool for this purpose; in fact, unless in very hard wood, there will be no necessity for previously boring a hole to receive the screw. When the screw is nearly home, the driver may be raised and the head driven to its seat. In removing a screw this driver is equally effective. One advantage of this device may not be apparent at first sight—that is, the absolute connection between the screw and driver, which will enable the workman to drive the screw into wood at any angle, perfectly governing its direction. The increased strength of the screw-head from this style of construction, the certainty of grip on the screw, and the entire control over the course of the screw, are the important features of this little device.

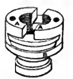
3465.



Silver's Hand Machine for Boring Wheel Hubs.—Fig. 3465 is a perspective view of a self-centring hub borer, which adjusts and holds the hub in position while being bored, and forms a square shoulder in the hub at the bottom of the bore. The chuck frame consists of three equidistant radial arms, having dovetailed slots in which slide the jaws A, having corrugated grips or faces for engaging with the surface of the wheel hub and holding it firmly. That portion of the jaw that projects above the radial arms is a nut B, in which works a screw, the outer end of which is squared to receive a wrench C, and the inner end carrying a bevelled pinion engaging with a bevel-gear turning loosely on the shank of the spider or jaw frame. By this means, whichever screw is turned, the two others, by the medium of the pinions on their ends, and the central gear, must have a common and simultaneous movement. Thus the jaws will be advanced to or receded from the centre in perfect accord, and bring the centre of the hub exactly coincident with the centre of the machine.

That portion of the jaw-chuck above the wheel D is screwed to a stock E, both being hollow to receive a boring mandrel F, carrying a cutter at its lower end. The upper portion of this mandrel is threaded with a screw of about ten to the inch, sufficient for ordinary feed for wood cutting, and has a handle similar to that of an auger. The feed-nut G with which the mandrel thread engages is of peculiar construction. It is seen plainly in Fig. 3466. The nut is in two halves, A, which slide in a dovetail slot cut across a circular bed-piece B. The whole is covered by the cap, Fig. 3467, and the half nuts are moved to or from the screw by a pin or screw in each projecting into semi-spiral slots A in the top of the cap. Pins on the lower portion of this cap are seated into an annular channel on the boss of B, Fig. 3466, so that the cap may be turned without lifting from place. This combined nut and cap is held in place in the stock E, when the machine is in use, by a thumb-screw H, Fig. 3465, that fits in an annular groove on the shank of the circular bed-piece or block B, Fig. 3466.

3466.



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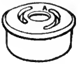

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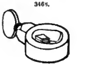
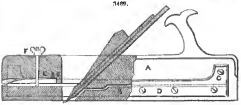


Fig. 3468 is a gauge for determining the depth of the hole to be bored; seen also at I, Fig. 3465. It has an oblong hole, a portion of its interior being threaded to fit the screw of the mandrel; and on the opposite side is a gib, also threaded on its end, fitting in a chamber, and moved to place by a thumb-screw. These opposite threaded portions prevent injury to the screw of the mandrel when the gauge is set up.

When a hub is to be bored, the gauge is secured on the mandrel at a proper height above the cap of the feed-nut to bore the required depth of hole in the hub. The hub being held in the jaws, the mandrel is turned, the tool being fed by the feed-nut at the top of the stock E, until the gauge comes in contact with the cap of the nut. The set screw H is then slightly loosened, which permits the feed-nut to turn with the mandrel, and a few turns of the handle forms a perfectly square shoulder at the bottom of the hole. To withdraw the mandrel from the bored hub, it is only necessary to give the cap of the feed-nut a slight turn to the left, separating the two halves of the nut, when the mandrel can be lifted out.

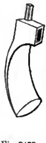
Improved Joiners' Plane.—The objects of the invention of G. Buckel, shown in Fig. 3469, are to give a control over the thickness of the shaving and depth of the cut by the pressure of the hand, and to prevent the drag of the bit on the board when the plane is drawn back. The stock of the plane is made in two parts, the upper portion A, which holds the bit, being pivoted to the lower part B at the rear end by a screw C passing through metal guide-plates D on each side the plane. The front end of the upper portion is raised from the lower portion by means of a spring E, which, when the pressure of the hand on the front of the plane is withdrawn, lifts the upper portion together with the bit or plane-iron. The amount of this movement is governed by the thumb-screw F.

3469.



Adzes, Axes, and Hatchets.—An adze is a hand-tool used by carpenters for chipping. It is formed with a thin arching blade, and has its edge at right angles to the handle. The edge is bevelled only on the inside, and the handle is easily removed when the tool is to be ground. Fig. 3470 is of a carpenter's adze; Fig. 3471 a ship-carpenter's adze; Fig. 3472 a cooper's adze;

3470.



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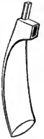

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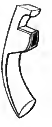
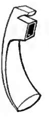


3473.



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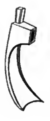

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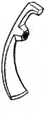

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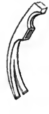
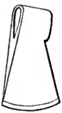


Fig. 3473 an improved wheeler's adze; Fig. 3474 a spout adze; Fig. 3475 a cooper's adze, with a hexagon eye; and Fig. 3476 a cooper's nail adze. This hand-tool, to be perfect, must have the centre of gyration of the moving mass in the cutting edge.

An axe is a hand-tool usually of iron, with a steel edge or blade, for hewing timber, chopping wood, and so on. It consists of a head with an arching edge, and a wooden helve or handle. Fig. 3477 is of a colonial felling axe; Fig. 3478 an Australian felling axe; Fig. 3479 a wheeler's axe; Fig. 3480 a north country ship-axe; Fig. 3481 a Dutch side-axe; Fig. 3482 a Brazil axe; Fig. 3483 a broad axe; Fig. 3484 a Kent axe; Fig. 3485 a Scotch axe; Fig. 3486 a blocking axe; Fig. 3487 a coachmaker's axe; Fig. 3488 a cooper's axe; Fig. 3489 a long felling axe; Fig. 3490 a common ship axe; and Fig. 3491 a Kentucky wedge-axe. This important tool must have either the centre of percussion or centre of gravity of the moving mass directly over and in the plane of the cutting edge. Fig. 3492 is of a Canada hatchet, handled; Fig. 3493 an American shingling hatchet, with claw; Fig. 3494 a shingling hatchet, with hammer head; Fig. 3495 an iron-handled butcher's cleaver; Fig. 3496 a bright meat chopper; Fig. 3497 a Norfolk and Suffolk single-edge bill, tanged and handled; Fig. 3498 a Yorkshire socket bill; Fig. 3499 a socket lopping bill; Fig. 3500 a Nottingham tanged bill, handled; and Fig. 3501 a strapped switch hook, single or double hand. When the cutting edge is required to throw chips, the plane passing

3482.



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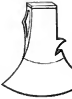

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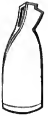

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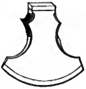

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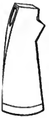

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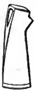

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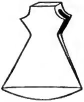

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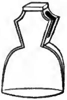

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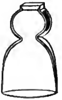

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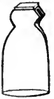

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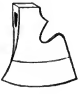

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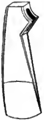

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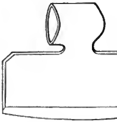

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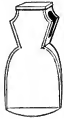

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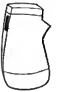

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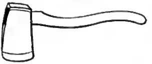

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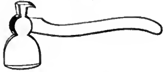
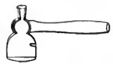


through the centre of percussion must also pass through the bevel, and not through the cutting edge of the blade.

3494.



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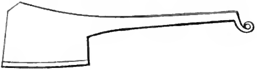

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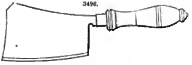

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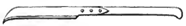

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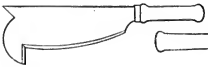

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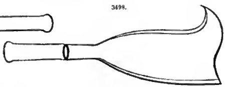

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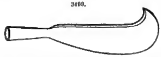

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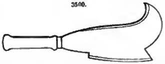
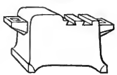


Anvils and Swage-blocks.—See Anvils. Fig. 3502 is an anvil for light edge-tools; Fig. 3503 an anvil for heavy edge-tools; Fig. 3504 a peculiar-shaped anvil, used in the forging of shears; Fig. 3505 a saw anvil; Fig. 3506 a sickle anvil; Fig. 3507 a pocket-knife blade anvil; Fig. 3508 a single hand file anvil; Fig. 3509 a table-knife blade anvil; and Figs. 3510, 3511, swage-blocks.

3502.



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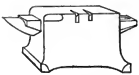

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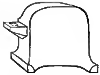

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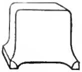

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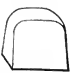

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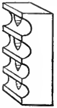

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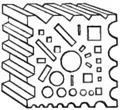

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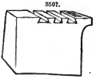

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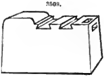

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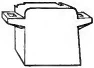
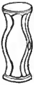


Tin and Coppersmiths' Tools.—Fig. 3512 is a block hammer; Fig. 3513 a concave hammer; Fig. 3514 a rivet set; Fig. 3515 a groove punch; Fig. 3516 a hollow punch; Fig. 3517 a teapot neck tool; Fig. 3518 a tea-kettle bottom stake; Fig. 3519 a kettle lid swage; Fig. 3520 a funnel stake; Fig. 3521 a side stake; Fig. 3522 a tinman and brazier's horse; Fig. 3523 a beck iron; Fig. 3524 a saucepan bellie stake; Fig. 3525 a grooving stake; Fig. 3526 a creasing iron.

3512.



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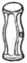

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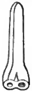

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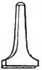

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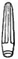

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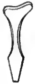

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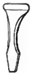

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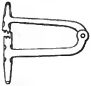

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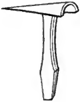

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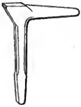

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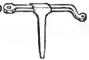

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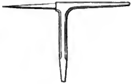

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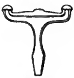

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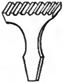

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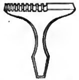
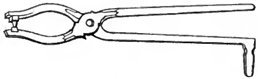


Fig. 3527 follies; Fig. 3528 stock shears; Fig. 3529 block shears; Fig. 3530 a bottom closing

3527.



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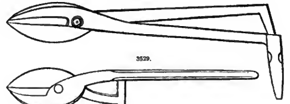
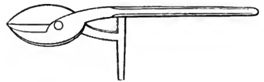
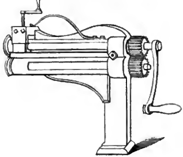


3529.



machine; Fig. 3531 goldsmiths' and dentists' rolls; Fig. 3532 a jeweller's mill; Fig. 3533 guillotine shears.

3530.



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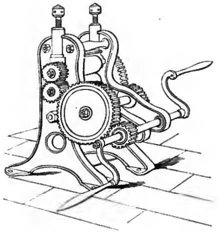

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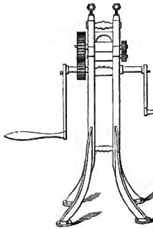

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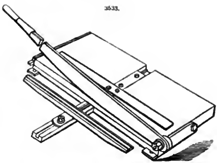
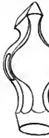


Hammers.—A hammer is an instrument for driving nails, beating metals, and the like, usually consisting of a metallic head fixed crosswise to a handle. See Steam-Hammer. Figs. 3534 to 3537 are forms of engineers' and mechanics' hammer-heads; Figs. 3538 to 3543 boiler-makers'

3534.



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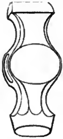

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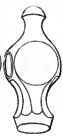

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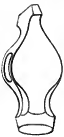

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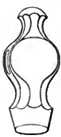

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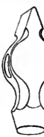
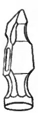


hammer-heads; Fig. 3544 a sledge hammer-head; Fig. 3545 a contractor's hammer-head for stonework; Fig. 3546 a hammer-head for riveting; Fig. 3547 a mason's hammer-head; Fig. 3584 a shingling hammer-head; Fig. 3549 a ship-carpenter's hammer-head; Fig. 3550 a coach-trimmer's

3540.



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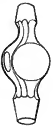

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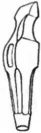

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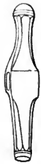

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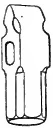

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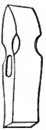

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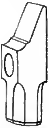

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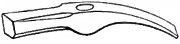

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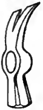

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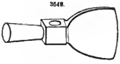

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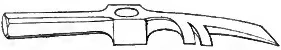

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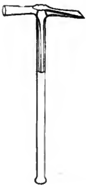

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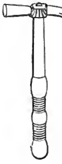

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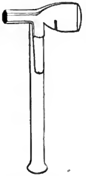

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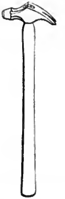

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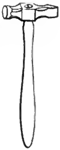
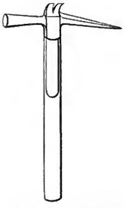


hammer-head; Fig. 3551 a saddler's hammer; Fig. 3552 a London glazier's hammer; Fig. 3553 a lathing hammer; Fig. 3554 a farrier's shoeing hammer; Fig. 3555 a plumber's hammer; Fig. 3556 a slater's hammer, with pick and claw; Fig. 3557 a brick hammer; and Fig. 3558 a fireman's hatchet or tomahawk.

3556.



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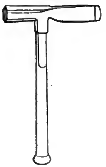

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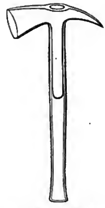
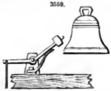


The handle of a hammer must be so formed and fixed that an operator may deliver blows without shock to his hand and arm; in this case the centre of percussion of both head and handle and the point struck must be in the line in which the centre of percussion is forced to move. It often happens that the centre of gravity or the centre of gyration of a hammer has to be directed on a given point; this is effected by giving to the head and handle peculiar shapes.

Fig. 3559 is an arrangement of a hammer for striking bells. The spring below the hammer raises it out of contact with the bell after striking, and so prevents it from interfering with the vibration of the metal in the bell.

Fig. 3560 is of a tilt or trip hammer. In this the hammer helve is a lever of the first order.

3559.



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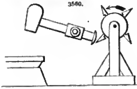

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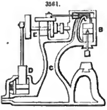

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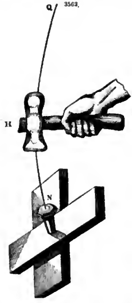


Fig. 3561 exhibits the mechanical combinations of Grimshaw's compressed air hammer. The head of this hammer is attached to a piston A, which works in a cylinder B, into which air is admitted—like steam to a steam-engine—above and below the piston by a slide-valve on top. The air is received from a reservoir C, in the framing, supplied by an air-pump D, driven by a crank on the rotary driving shaft E.

The succeeding examples indicate how the power of hammers may be calculated.

Example.—Suppose a hammer H, Fig. 3562, strikes a nail N, and drives it $\frac{1}{4}$ of an inch, the hammer weighs 11·58 lbs., and in delivering the blow it passes over the space Q N = 10 ft. in a second; required the force in pounds delivered by the hammer upon the head of the nail. 10 ft. : 1″ :: $\frac{1}{48}$ ft. : $\frac{1}{480}$″. Hence the time occupied in driving the nail $\frac{1}{4}$ of an inch cannot be less than $\frac{1}{480}$ of a second = t.

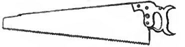
$$m = \frac{11 \cdot 58}{32\frac{1}{6}} = \cdot 36\,; \qquad \therefore \quad \mathrm{F} = \frac{m}{t} \times v = \cdot 36 \times 480 \times 10 = 1728 \text{ lbs.}$$

∴ The force in pounds delivered upon the head of the nail is nearly = a ton.

Let us take another example, and suppose a large hammer, weighing 1930 lbs., moving with a velocity of 40 ft. a second, and to strike a mass of iron which it indents; the indentation is $\frac{1}{8}$ in. deep with a surface area of 16 sq. in.; after the blow is struck the hammer rebounds 2·5 ft. What is the force in pounds delivered on the sq. in. by a blow of this hammer? $\frac{1}{8}$ in. = $\frac{1}{96}$ of a foot; then 40 ft. : 1″ :: $\frac{1}{96}$ ft. : $\frac{1}{960}$″; hence the time occupied in making the indentation cannot be less than $\frac{1}{960}$ of a second. But $\mathrm{F} = \frac{m}{t} \times v$. (See Essential Elements of Practical Mechanics, by the Editor of the present work.) The mass of this hammer = $\frac{1930}{32\frac{1}{6}} = 60$; then in this case $\mathrm{F} = \frac{m}{t} \times v = 60 \times 960 \times 40 = 2304000$ lbs., which is the force in pounds delivered upon 16 sq. in. $\therefore \frac{2304000}{16} = 144000$ lbs. on each square inch. $\frac{40^2 \times 1930}{32\frac{1}{6}} = 96000$ units of work in the hammer (Essential Elements of Mechanics, p. 97). 1930 × 2·5 = 4825 units of work in the rebound of the hammer; hence 96000 − 4825 = 91175. Then if x be the area $\frac{1}{96}$ ft. the depth of the iron displaced by the blow, we have $x \times 144000 \times \frac{1}{96} = 91175$ units of work. $\therefore x = 15 \cdot 196$ sq. in. the area for a uniform depth of $\frac{1}{8}$ in., as if the iron was displaced by a punch.

Saw.—A saw is an instrument for cutting and dividing substances, as wood, iron, and so on, consisting of a thin plate or blade of steel, with a series of sharp teeth on one edge which remove successive portions of the material by cutting or tearing. See SAWS AND SAWING MACHINERY.

3563.



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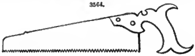

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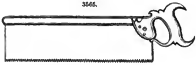

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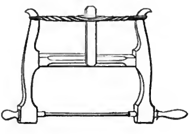

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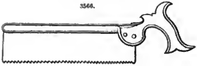

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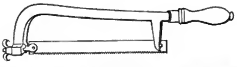
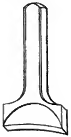


Fig. 3563 is a hand, panel, and ripping saw; Fig. 3564 is a grafter saw; Fig. 3565 a tenon saw; Fig. 3566 a dovetail saw; Fig. 3567 an iron bow-saw; and Fig. 3568 a turning saw in its frame.

Coopers' Tools.—One of the few things that man has perfected is the barrel, hogshead, or cask; it can be filled, emptied, and removed from place to place with greater ease than any other form of body containing an equal quantity. Figs. 3569 to 3571 are of coopers' drivers for tightening the hoops of a cask; Fig. 3572 a cooper's punch; Fig. 3573 a cooper's chisel; Fig. 3574 a hung borer; Fig. 3575 a cooper's froe; Fig. 3576 is a cooper's two-hand round shave; Fig. 3577 a cooper's round shave; Fig. 3578 a cooper's shave, and Fig. 3579 a cooper's shave-iron; Fig. 3580 a common spokeshave, and Fig. 3581 a common shave-iron; Fig. 3582 a cooper's jigger knife;

3569.



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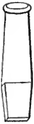

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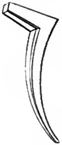

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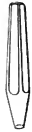

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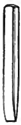

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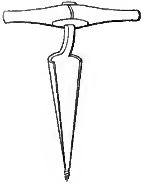

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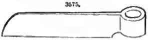

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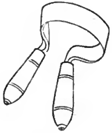

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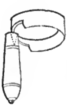

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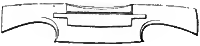

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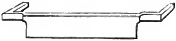

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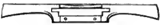

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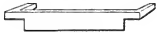

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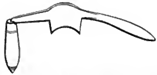

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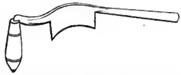
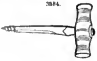


Fig. 3583 a London jigger knife; Fig. 3584 a brewer's gimlet; Fig. 3585 a cooper's vice; Fig. 3586 a cooper's bick-iron, used principally for punching holes in hoop iron; and Fig. 3587 a cooper's flagging iron.

3584.



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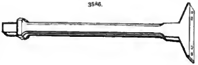

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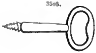

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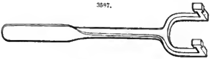

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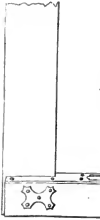

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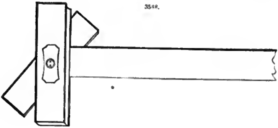

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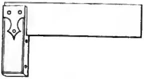

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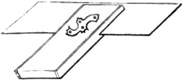

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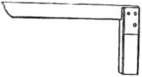

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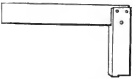

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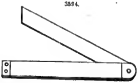
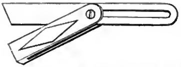
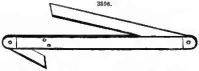


Squares and Bevels.—Fig. 3588 is a T drawing square; Fig. 3589 an ordinary square, with a level attached; Fig. 3590 a common brass-mounted square; Fig. 3591 a mitre square; Fig. 3592 a bricklayer's square, London pattern; Fig. 3593 a brass-stocked sash square; Fig. 3594 an angle bevel; Fig. 3595 an improved metallic frame sliding bevel; and Fig. 3596 a boat-builder's bevel with two brass blades.

3595.

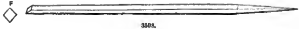


3596.

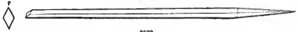


Engravers' Tools.—Fig. 3597 is of a square graver; Fig. 3598 a lozenge graver; Fig. 3599 a flat-edge graver; Fig. 3600 a bent square graver; Fig. 3601 a bent lozenge graver; Fig. 3602 a round graver; Fig. 3603 an oval graver; Fig. 3604 an engraver's knife; Fig. 3605 a flat oval graver; Fig. 3606 a flat engraver's chisel; Fig. 3607 a half-round bent engraver's chisel; Fig. 3608 a flat

3597.



3598.



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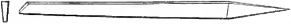

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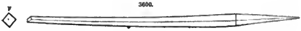

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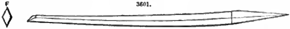
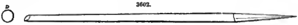
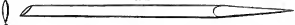


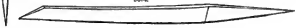
3602.



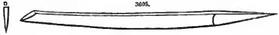
3603.



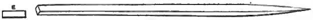
3604.



3605.



3606.



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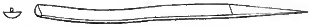

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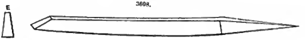
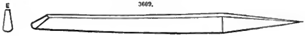
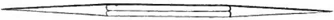


3609.



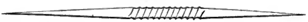
scooper; Fig. 3609 a round scooper; Fig. 3610 a double needle; Fig. 3611 an etching point; Fig. 3612 a twisted etching point; Fig. 3613 a scraper; Fig. 3614 an oval burnisher; and Fig. 3615 a round burnisher, bent.

3610.

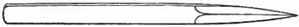


3611.

3612.

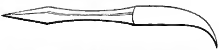


3613.



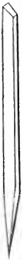
3614.

3615.

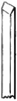


Metal-turning Tools.—The turning of metal is effected by a slow motion, comparatively speaking, with respect to the turning of wood, ivory, or bone, which require in most cases a rapid motion; yet wood-turning tools require a less obtuse angle to form the cutting edge than the tools employed to turn iron, brass, or steel. The planes forming the cutting edge of metal-turning tools make a solid angle which generally exceeds 60°. Figs. 3616 to 3632 are of a set of turning tools for metal, Figs. 3631, 3632, being especially for screw cutting.

3616.



3617.



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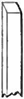
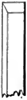
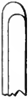


3619.



3620.



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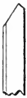
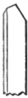


3622.



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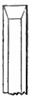

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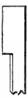
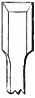
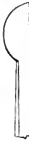


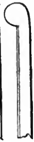
3625.



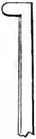
3626.



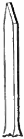
3627.



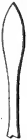
3628.



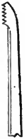
3629.



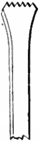
3630.



3631.



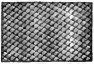
3632.



Files and Rasps.—A file is a steel instrument having the surface covered with sharp-edged furrows or teeth, used for abrading or smoothing other substances, as metals, wood, and so on. A *file* differs from a *rasp*, in having the furrows made by straight cuts of a chisel, either single or crossed, while the rasp has coarse, single teeth, raised by the pyramidal end of a triangular punch.

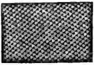
A *bastard file* is a file intermediate between the coarsest and the second cut. Figs. 3633 to 3650 show the various cuts of files and rasps 12 in. long; the cuts of longer and shorter files are larger and smaller in proportion. See FILE-CUTTING MACHINERY.

3633.



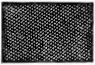
Rough.

3634.



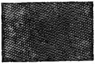
Middle.

3635.



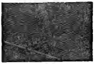
Bastard.

3636.



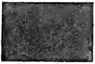
Second Cut.

3637.



Smooth.

3638.

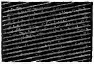


Dead Smooth.

3639.

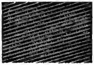
Rough.

3640.



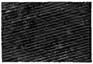
New Cut.

3641



Middle.

3642.

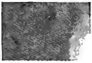


Bastard.

3643.

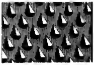
Second Cut.

3644.



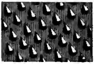
Smooth.

3645.



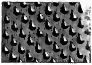
Horse.

3646.



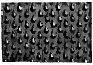
Rough.

3647.



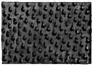
Middle.

3648.



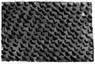
Bastard.

3649.



Second Cut.

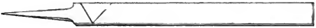
3650.



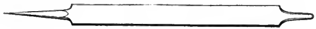
Smooth.

Fig. 3651 is of a smooth needle file; Fig. 3652 a round-off file; Fig. 3653 a three-square taper file; Fig. 3654 a bastard knife file; Fig. 3655 a bastard rifller; Fig. 3656 a saddle-tree rasp; Fig. 3657 a round rasp; Fig. 3658 an improved shoe rasp; Fig. 3659 a horse mouth rasp.

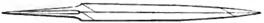
3651.



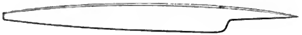
3652.



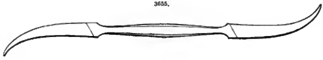
3653.



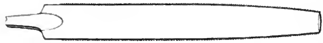
3654.



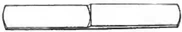
3655.



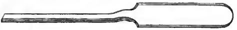
3656.

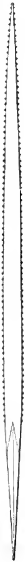


3658.



3659.



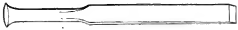


3657.

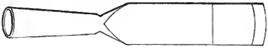
The effective power of the file resembles that of the saw, which has the power of a wedge not encumbered by the friction of one of the faces. The angle of the faces of the wedge is formed by the direction of the applied power and a tangent to the teeth. The diagonal position of the furrows of the file gives an additional shearing wedge power.

Chisels, Gouges, and Planes.—Fig. 3660 is of a shipwright's sharp iron chisel; Fig. 3661

3660.

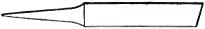


3661.

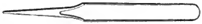


a ship slice; Fig. 3662 a turning chisel; Fig. 3663 a turning gouge; Fig. 3664 a bookbinder's plough knife; Fig. 3665 a common plane-iron; Fig. 3666 a round nose plane-iron; Fig. 3667 a cut plane-iron; Fig. 3668 a round nose double plane-iron; Fig. 3669 an ordinary double plane-iron;

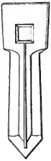
3662.



3663.



3664.



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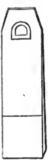

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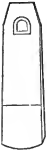

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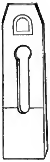

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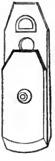

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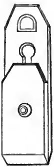

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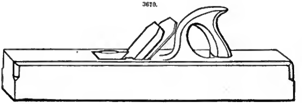

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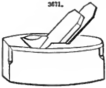

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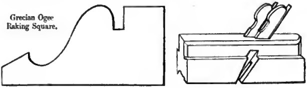

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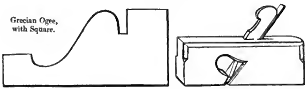
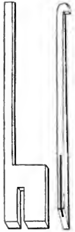


Fig. 3670 a trying plane; Fig. 3671 a smoothing plane; Fig. 3672 an ovolo sash plane, to stick and rebate; Fig. 3673 a rabbet or square plane with skew eye; Fig. 3674 grooving irons; Fig. 3675 a cooper's jointer iron; Fig. 3676 a coachmaker's T iron; Fig. 3677 a skew rabbet iron;

Fig. 3678 hollow and round rabbet irons; Fig. 3679 a striking knife; Fig. 3680 a carpenter's drawing knife; Fig. 3681 a cooper's staff knife; Fig. 3682 a mast shave; Fig. 3683 a London cooper's hollowing knife; Fig. 3684 a common chisel; and Fig. 3685 a common gouge, fixed to its handle.

3674.



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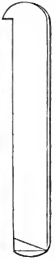

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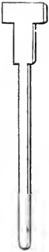

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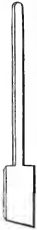

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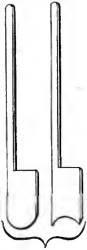

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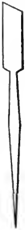

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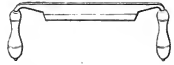

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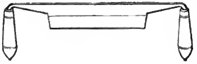

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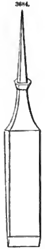

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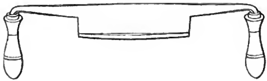

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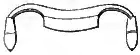

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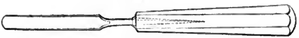
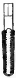


Stocks, Dies, Bits, and Braces.—Figs. 3686 to 3697 show a double-handed screw stock, with four pairs of dies, and four each of taper and plug taps; Fig. 3698 a clock screw plate; Fig. 3699 a double-handed screw plate with taps; Fig. 3700 Whitworth's screw stock; Fig. 3701 an ordinary brace; Fig. 3702 a Scotch iron brace; Fig. 3703 a plated brace; Fig. 3704 a plug centre bit;

3686.



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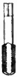

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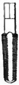

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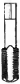

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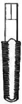

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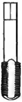

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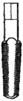

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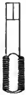

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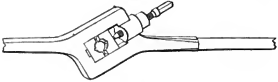

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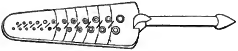

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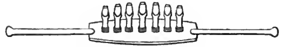

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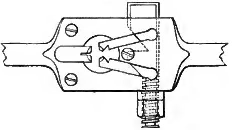
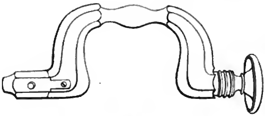


Fig. 3705 a snail horn countersink; Fig. 3706 a rose-head countersink; Fig. 3707 a flat-head countersink; Fig. 3708 a brace turnscrew; Fig. 3709 a bobbin bit; Fig. 3710 a taper bit; Fig. 3711 a sash bit; Fig. 3712 a shell bit; Fig. 3713 a nose bit; Fig. 3714 a spoon bit; Fig. 3715 a square rinder; Fig. 3716 a half-round rinder; Fig. 3717 a gimlet bit; Fig. 3718 a cooper's dowling bit; Fig. 3719 a universal ball ratchet brace; Fig. 3720 a self-feeding ratchet brace; Fig. 3721 a treble-motion ratchet brace; Fig. 3722 Calvert's ratchet brace;

3701.



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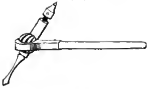

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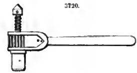

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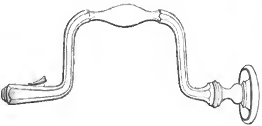

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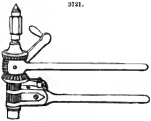

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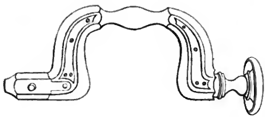

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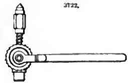

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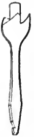

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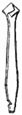

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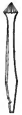

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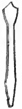

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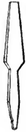

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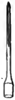

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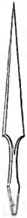

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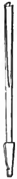

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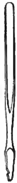

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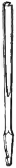

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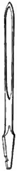

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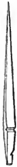

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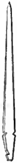

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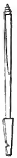

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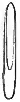
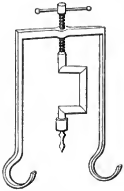


Figs. 3723 to 3725 are drill stocks of various kinds; Fig. 3726 a gas-pipe wrench for iron pipe, with three different sized claws; Fig. 3727 a gas-pipe tongs for iron pipe.

3723.



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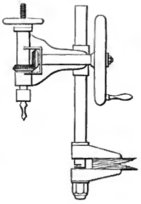

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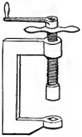

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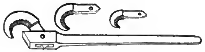

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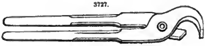
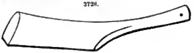


Plumbers' Tools.—Fig. 3728 is of a hornbeam dresser; Figs. 3729, 3730, bossing mallets; Figs. 3731, 3732, copper bits; Figs. 3733 to 3736 soldering and bossing irons; Fig. 3737 a ladle; Fig. 3738 a double sucker hook.

3728.



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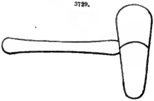

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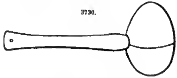

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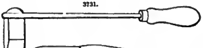

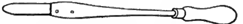

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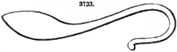

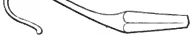

3734.

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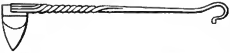
3735.



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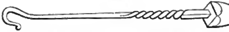

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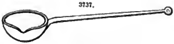
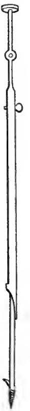


Print Cutters' and Carvers' Tools.—Fig. 3739 is a black carving chisel; Fig. 3740 a skew carving chisel; Fig. 3741 a flat black carving gouge; Fig. 3742 a medium black carving gouge; Fig. 3743 a black carving gouge for scribing; Fig. 3744 a deep black carving gouge; Fig. 3745 a black straight fluting gouge; Fig. 3746 a black bent fluting gouge;

3738.



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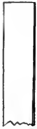

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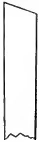

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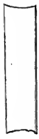

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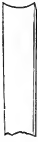

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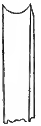

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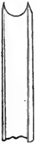

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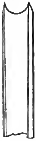

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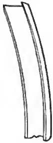

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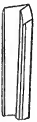

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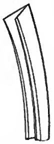

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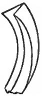

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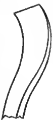

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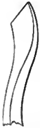

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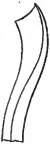

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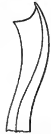

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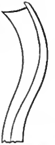

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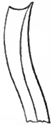

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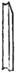

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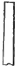
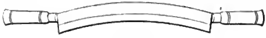


Fig. 3747 a straight parting tool; Fig. 3748 a bent parting tool; Fig. 3749 a spoonbit parting tool; Fig. 3750 a spoonbit or entering chisel; Fig. 3751 a skew spoonbit or entering chisel; Fig. 3752 a medium black carving gouge; Fig. 3753 a spoonbit or entering gouge for scribing; Fig. 3754 a deep spoonbit or entering gouge; Fig. 3755 a back bent spoonbit or entering gouge; Fig. 3756 a veining tool; and Fig. 3757 an unshouldered print cutter's chisel.

Tanners and Curriers' Hand-Tools.—Figs. 3758, 3759, tanners' knives; Fig. 3760 a currier's knife; Fig. 3761 an improved currier's knife with screws; Fig. 3762 a skinner's round moon knife; Fig. 3763 a saddler's knife; Fig. 3764 a ship scraper.

3758.



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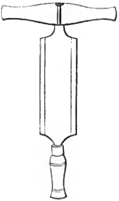

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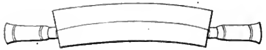

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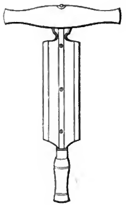

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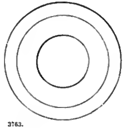

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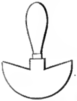

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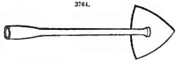
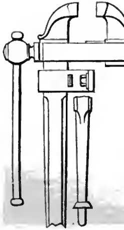


Miscellaneous Hand-Tools.—Fig. 3765 a boiler bear; Fig. 3766 a boiler cramp; Fig. 3767 an improved cramp for joiners, pattern makers, wheelwrights, or railway carriage builders; Fig. 3768

3768.



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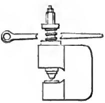

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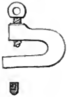

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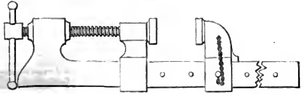
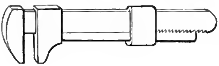


a wrought-iron parallel vice; Fig. 3769 an improved spanner; Fig. 3770 Fenn's spanner; Figs. 3771, 3772, screw-keys; Fig. 3773 a key spanner; Fig. 3774 Clyburn's spanner; Fig. 3775 Budding's

3769.



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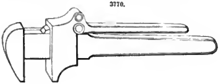

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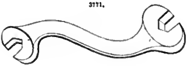

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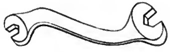

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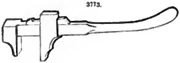

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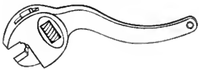

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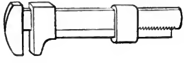

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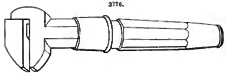

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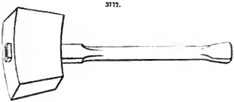

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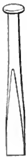

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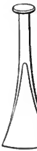

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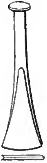

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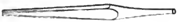

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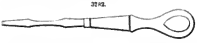
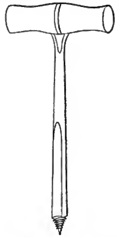


spanner: Fig. 3776 an improved cylinder wrench; Fig. 3777 a joiner's or carpenter's mallet; Figs. 3778 to 3780 calking irons; Fig. 3781 a brad or nail punch; Fig. 3782 a turnscrew, London pattern; Fig. 3783 a spike gimlet; Fig. 3784 a wheeler's gimlet; Fig. 3785 a cutting gauge, the head faced with brass; Fig. 3786 an improved cutting gauge; Fig. 3787 a thumb or turnscrew

3783.



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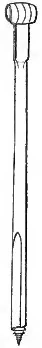

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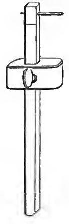

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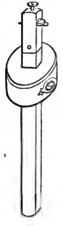

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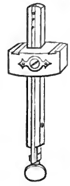

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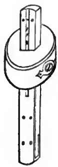

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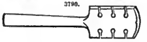

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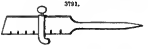

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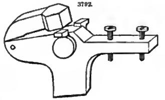

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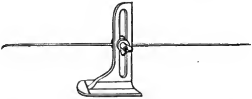

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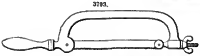

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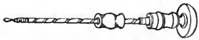
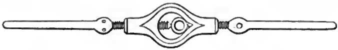


screw-slide mortise gauge; Fig. 3788 an improved mortise gauge with improved stem; Fig. 3789 a scribing block; Fig. 3790 a hand saw set; Fig. 3791 a slide saw set; Fig. 3792 an improved saw set; Fig. 3793 an iron bow saw; Fig. 3794 is an Archimedian brace; Fig. 3795 a gas-pipe cutter for iron pipe; Fig. 3796 a lathe carrier; Fig. 3797 joiners' pincers; Fig. 3798 shoe nippers with box joint; Fig. 3799 shoe nippers; Fig. 3800 shoe pincers; Fig. 3801 a tinman's pliers; Fig. 3802 shoe punch pliers; Fig. 3803 upholsterers' pincers; Fig. 3804 clock pliers; Fig. 3805 round-nosed

3795.



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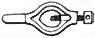

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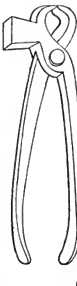

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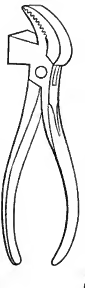

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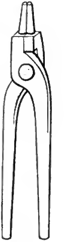

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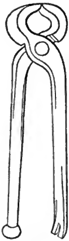

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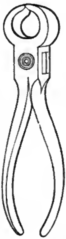
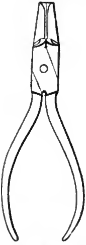


3804.



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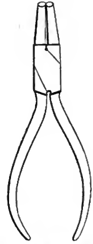

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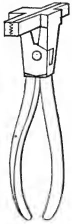

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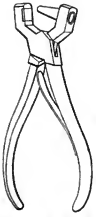
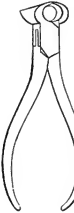


clock pliers; Fig. 3806 cutting nippers; Fig. 3807 nipper pliers; Fig. 3808 vice chop sliding tongs; Fig. 3809 sliding dog-nosed tongs; Fig. 3810 an improved saw set; Fig. 3811 a bent carpet strainer; Fig. 3812 a pinking iron; Fig. 3813 a box whirl drill stock.

Compasses and Callipers.—Fig. 3814 plain compasses; Fig. 3815 wing compasses; Fig. 3816 spring callipers; Fig. 3817 inside and outside callipers; Fig. 3818 improved inside and outside callipers; Fig. 3819 engineers' beam dividers; Fig. 3820 is a decimal *cam* gauge. The eccentricity of a movable cam which is finely graduated shows the diameter of any small body which is held between a circular movable pin and the edge of the cam. The index always points to the centre of the circular pin or stud, and shows the normal distance between the surface of that stud and the surface of the cam. See COMPASSES.

3806.



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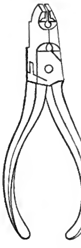

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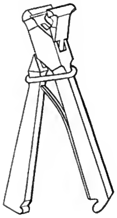

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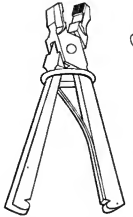

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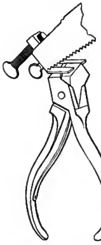

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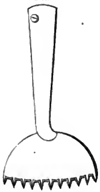

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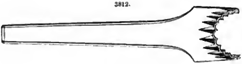

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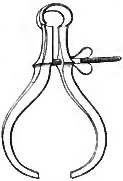

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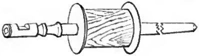

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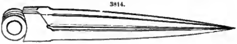

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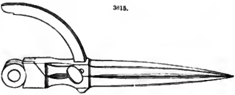

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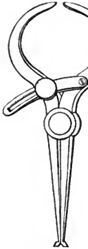

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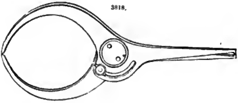

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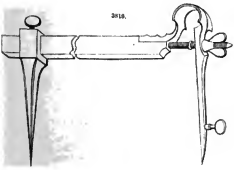

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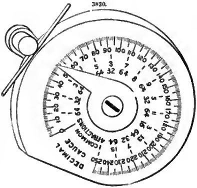
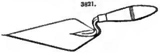


Trowels.—Fig. 3821 is of a mason's trowel; Fig. 3822 a London brick trowel; Fig. 3823 a pointer's cutting trowel; Fig. 3824 plasterers' trowels; Figs. 3825, 3826, plasterers' moulding tools.

3821.



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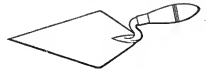

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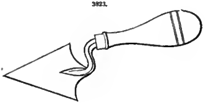

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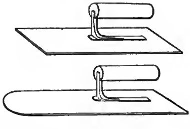

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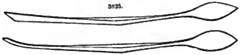
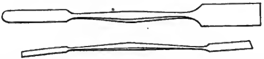
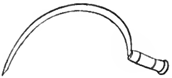




3826.

Sickles, or *Reaping Hooks.*—Fig. 3827 is of the form of reaping-hook used in Yorkshire and the North of England; Fig. 3828 a Welsh hook; Fig. 3829 a Kent hook; Fig. 3830 an English

3827.



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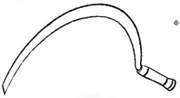

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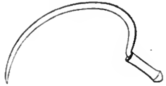

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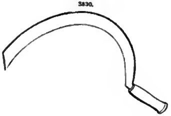
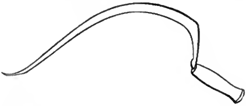


bagging hook; Fig. 3831 an Irish sickle with square heel; Fig. 3832 a bean hook; Fig. 3833 a pea hook; Fig. 3834 a United States' Yarrick sickle; Fig. 3835 a Russian sickle; Fig. 3836 a Spanish sickle; Fig. 3837 a German sickle; Fig. 3838 a Poland sickle. The sickle has the power of the cam and saw combined; it acts on a small sheaf or hundle of grain collected by the left hand and the bay near the handle of the instrument; the small sharp teeth which point to the reaper do not retard the process of gathering the grain. The reaper with his right hand draws the sickle towards him and brings the hollow toothed-cam into contact with the stalks, which he cuts, or rather saws, with great ease on account of the shape of the instrument and his own physical formation. Fig. 3839 is of an ordinary sheep-shears; Fig. 3840 an improved sheep-shears. See Agricultural Implements.

3831.



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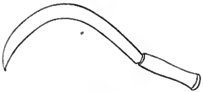

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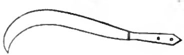

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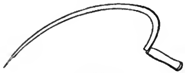

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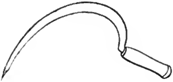

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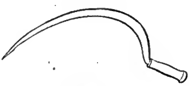

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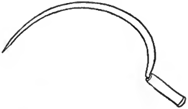

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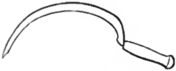

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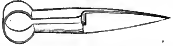

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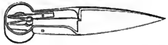
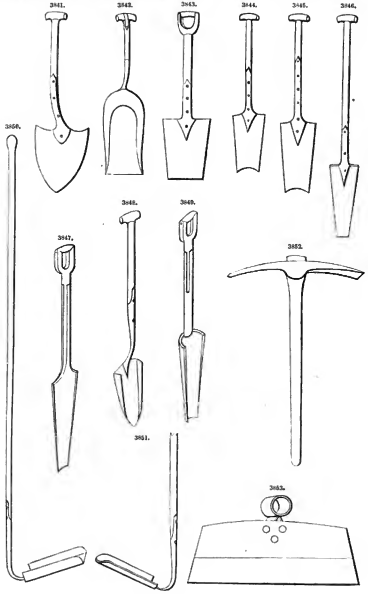


Spades, Shovels, and Scoops.—Fig. 3841 a gravel shovel with long strap; Fig. 3842 a tender or locomotive shovel; Fig. 3843 an imperial Scotch spade; Fig. 3844 a soughing spade; Fig. 3845 a soughing tool; Fig. 3846 a long-handled Irish spade; Fig. 3847 a deep draining tool; Fig. 3848 a mud shovel; Fig. 3849 a bottoming spade; Fig. 3850 a flat scoop; Fig. 3851 a draining hoe; Fig. 3852 is of a pick-axe; Fig. 3853 is of an ordinary hoe.

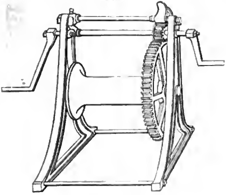


3841. 3842. 3843. 3844. 3845. 3846. 3850. 3848. 3849. 3847. 3852. 3851. 3853.

Fig. 3854 is of a lifting or hoisting crab; Fig. 3855 an improved traversing jack; Fig. 3856 Haley's screw-jack; Fig. 3857 a tripod jack.

We have represented with geometrical accuracy hand-tools of great durability, formed to effect the objects for which they are designed with ease, accuracy, and precision. Most of our illustrations are of tools manufactured by Alexander Mathieson and Son, of Glasgow, who, as tool-makers, stand first in the first class. This firm have reduced the hardening and tempering of hand-tools to a science, which can only be acquired by much thought and an extensive experience; their planes and boring tools, in particular, have acquired a well-deserved and extensive fame. There are many points of excellence in the larger tools manufactured by Mathieson and Son to which we shall hereafter refer in our article Machine Tools.

3854.



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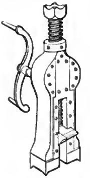

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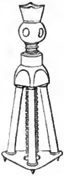

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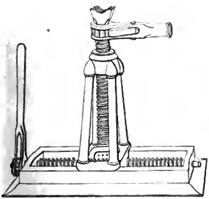

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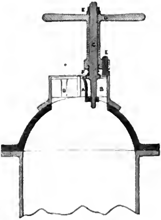

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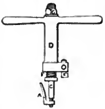
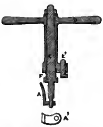


3860.

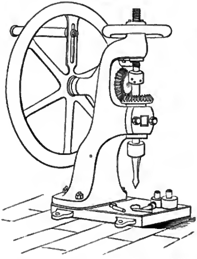


Knifing Machine, Figs. 3858 to 3860, invented by J. F. Stephenson. This design is new, and possesses many advantages over the mode generally in use, namely, chucking on the lathe. One man is able to set this tool, Fig. 3858, and face two valve-seats in about an hour, and without breaking the dome-cover joint. Fig. 3858 is a cross-section of a dome cover, with the tool in position for working. Fig. 3859 is an elevation of the tool itself. Fig. 3860 is a section, showing the knife for cutting the mitre. A', Fig. 3859, is a plan of nut A. The action is easily explained:

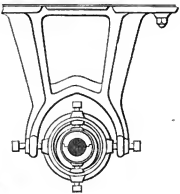
thus, referring to Fig. 3858, hold the nut A by the stalk and pass it under the bridge of the valve-seat B; screw the pillar C into the nut A, then place the box handle D, which carries the cutter E, which is bored out to receive the spring F, on to C. Screw the nut G, Fig. 3859, to supply the feed to E, then the tool is in perfect order for facing the top of the valve-seat; when that is completed, change the cutter E, and insert another cutter E′, as shown in Figs. 3858 to 3860, to give the proper mitre for the valve to rest upon. This tool is valuable in railway establishments, as safety-valve seats frequently require facing.

Fig. 3861 is of a hand-power bench drilling machine, by Moir and Co., of Manchester, capable of drilling holes ¾ in. diameter, 3 in. deep, in wrought or cast-iron and steel, up to 1 ft. diameter by hand-power. consisting of independent framing, securely bolted to the foundation, which serves as a table for articles to rest upon while under operation. This hand-tool has a cast-steel spindle, with parallel bearings, and feed-motion attached; it is worked by a square-thread screw and hand-wheel at the top of the machine. It is furnished with a large fly-wheel, adjustable handle, and wood ferrule. It has a driving shaft and bevel-gearing for the spindle, and chucks for holding the drills and nut-keys. See AGRICULTURAL IMPLEMENTS. ALLOYS. ANVIL. ARTESIAN WELL. AUGER, p. 203. AWL. BARROW. BATEA. BELLOWS. BENCH. BLAST FURNACE. BORING AND BLASTING. CONSTRUCTION, p. 1034. CROWBAR. ELECTRO-METALLURGY. FORGE. GRINDSTONE. MACHINE TOOLS.

3861.



3862.



HANGER. FR., *Palier pendant*; GER., *Hängelager*; ITAL., *Sostegno sospeso*; SP., *Soporte suspendido*.

When hangers with long bearings were first introduced, the attempt was made to use long boxes for line and countershaft journals, as well as for all others, but the warping and shrinkage of the girders and ceiling joints to which hangers are almost invariably secured soon threw the boxes out of line, and had a tendency to bind the shafting, and left no alternative but to return to the short box, unless some device could be found whereby the box would be free to adjust itself to the shaft regardless of the position of the body of the hanger. Among a variety of contrivances designed to accomplish the above object an application of the universal-joint arrangement was considered the best, as it is one of the cheapest, of all that possess the necessary requirements.

The manner of applying the principle to line-shaft hangers is shown in Fig. 3862. The box, being secured within the ring and between the two arms of the hanger by the four set screws, is free to turn in any direction, and the clearance between the different parts admits of its being moved sideways, or up and down, so as to bring the shaft into exact line when the bodies of the different hangers are nearly in the required position. A section of box, ring, and drip-cap is shown at Fig. 3863, which may be used as shown in Fig. 3862, or in a bracket of the form shown at Fig. 3864, or in a plummer-block, Fig. 3865.

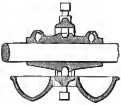
At Figs. 3866, 3867, a countershaft hanger is shown in which the same self-adjusting device is employed, but as only two set screws instead of four are used, the boxes are not adjustable. When these hangers are in use it has been the practice to make the journals from 3½ to 4 diameters in length, to chamber out the boxes, and line them with anti-friction metal.

At Figs. 3868, 3869, a self-lubricating journal-box, applicable to the same hanger, is shown, in which it is proposed to return the oil from the drip-cup to the shaft by means of the two loose rings, A A.

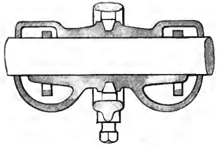
Figs. 3870, 3871, show a line-shaft coupling, which, with the exception that the cones are liable to stick fast, may well be pronounced faultless. This method was first introduced by

C. F. T. Young. A device, whereby it is proposed to overcome this one difficulty, is shown in Fig. 3870, and consists simply in having a tapped hole through the shell of the coupling, into which a conical-pointed set screw may be inserted for forcing the cones out of their seat.

3863.



3868.



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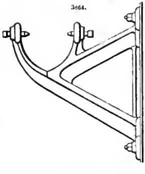

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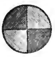
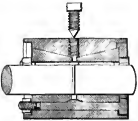


3870.



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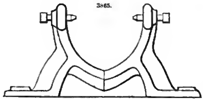

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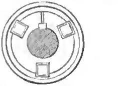

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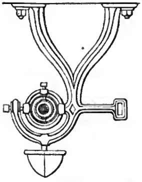

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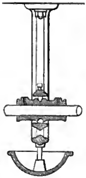

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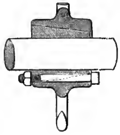
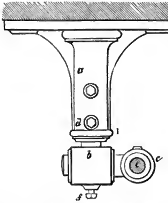


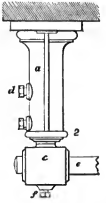
Fig. 3872 is of a method of securing pulleys to shafting by means of a split cone and one or more bolts. The advantages of this arrangement are, that the pulleys can be set at any point in the shaft without disfiguring it with key-ways or set-screw marks, that they will run true when set, and that they can be changed to different sized shafts by simply changing the cones.

C. F. T. Young gives credit to A. Shanks as the original inventor of the system of hangers illustrated in Figs. 3873, 3874. The hanger employed by Shanks in 1848 is shown in Figs. 3873, 3874; *a* is the hanger; *b* is the portion carrying the bearing for the shaft; *c*, the bearing; *d d*, the

3873.



3874.



set screws by which the line of the shaft can be readily adjusted; *e*, end of the shaft; and *f*, the set screw by which the horizontal position of the shaft and bearings is adjusted. By this means vertical, horizontal, and all other motions are attained, and the shaft thereby easily set and maintained in its proper position with very little trouble.

HARBOUR. FR., *Port;* GER., *Porten;* ITAL., *Porto;* SPAN., *Puerto.*

THE ALBERT HARBOUR AT GREENOCK.—The following account of this harbour is taken from the Minutes of P. I. C. E., 1863. The minute to which we allude is No. 1082, entitled "Structures in the Sea, without Coffer-dams," by Daniel Miller.

In bringing forward this paper the engineering objects D. Miller had in view were to treat of the various methods of constructing the foundations of quay-walls, piers, or breakwaters, for the formation of docks and harbours in deep water; to describe works of this kind carried out on principles different from those usually practised; and to point out the further application of these principles to other works of a similar nature.

The formation of these works has usually required the adoption of very expensive means; and an easy and economical mode of building such structures, so as to combine the various conditions necessary to ensure solidity and capability of resisting the mechanical forces to which they are subjected, and also the destructive action of exposure to the elements, the boring of marine worms, or the corrosive action of salt water, has been hitherto a desideratum.

Several methods of founding works in deep water have been practised; but there are objections to most of these systems, arising either from their expensive nature or from defects in the durability of the structures. The plans which have been employed are;—

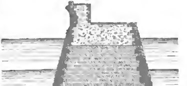
Founding on piling carried up to about the level of low water;
Constructing within caissons or coffer-dams; and
Building under water by means of diving apparatus.

The first method has serious defects, both in deficiency of strength and of durability, as the piling is often insufficient to resist the lateral pressure from behind the wall, and the heads of the piles being exposed to the alternate action of air and water soon decay, when the weight of the wall above rapidly completes the failure of the whole structure. Where there are marine worms this mode is quite inapplicable. Instances of the failure of such works will occur to many. Referring to the Clyde River, for example, nearly all the older quay-walls of the harbour of Glasgow were built on this principle, and have given way from the decay of the piles, or have required very expensive repairs to keep them up; and at Port Glasgow Docks the walls, which were also built on that system, gave way from the lateral pressure forcing them out shortly after completion, greatly to the injury of that port.

The most usual mode adopted, where works of great solidity are required, is to resort to coffer-dams and to pump out the water from the enclosed space, so that the foundations and the walls may be constructed as on dry land. This is certainly most effectual, but it is at the same time generally expensive, and it is often not unattended with danger. In many cases, too, from the nature of the strata, it is almost impossible to form an effective coffer-dam. The construction of coffer-dams, moreover, frequently requires much engineering skill, besides involving great expense; and when it is considered that they are only wanted for a temporary purpose, it must be conceded that it is an object of great importance to devise some mode by which their use can be obviated, and solid and durable works can be executed without their aid.

The system of building under water by means of *diving bells* and *diving dresses* has been practised to a considerable extent, and the improved apparatus now used gives great facilities for this kind of work; but it is only applicable under particular circumstances, and it is also costly, besides being liable to cause delay in the progress of the work. The Dover Breakwater, Fig. 3875, is an example on a large scale of this mode of construction, but it is also an instance of the vast sums which may be expended on this system.

3875.



In *bridge* building a great innovation has been made in the construction of the piers without the aid of coffer-dams, and the French engineers have been, until lately, in advance of this mode of constructing such works. The plan they pursue was introduced by Vicat in 1813; it consists in forming enclosures of close piling, or "caisses sans fonds," of the shape of the pier, up to about low-water level, and filling in with hydraulic concrete, or beton, on which the upper part of the piers is built in the usual manner. Some important bridges in France, and many of those across the Seine at and near Paris, such as the Carrousel, Jena, Austerlitz, Alma, and Asnières, have the piers formed in this way without coffer-dams. These works of the French engineers, however, being in some instances a combination of timber and concrete, cannot be said to possess substantiality and durability, and a change was necessary in order to enable them to compete with stone structures built in the usual manner. The modes recently adopted in constructing the piers of the Westminster and the Chelsea Bridges without coffer-dams have effected this, and these works are examples of success in departing from rules without reason, and in applying scientific principles to the practice of bridge building.

Application of Concrete.—In this mode of construction, béton or hydraulic concrete has played an important part, and it also forms a leading feature in the plans for marine works.

Concrete, though employed in Roman and mediæval times, was allowed to go out of use, and since then it has not until recently been much recognized as a constructive material by the engineers of this country, who have, for marine purposes, placed their faith chiefly in works of cyclopean masonry, constructed within coffer-dams, or built under water by the *diving bell*. The French engineers deserve the credit of having been, for a longer period in modern times, alive to the value of beton as an important auxiliary in hydraulic works.

For some time, however, its value has been more appreciated in England as a substitute for masonry, and it has been employed in some important works. Still, its use is chiefly confined to forming a homogeneous and monolithic-bearing stratum for foundations, and not properly speaking as a constructive material, to which latter purpose it is more especially the author's object to direct attention. In particular, there are but few examples of the application of liquid concrete deposited and allowed to set in the water in the construction of submarine works.

There are three modes in which concrete may be applied for constructive purposes.—building it in mass and allowing it to set before water has access to the work, as has been adopted in the construction of the walls of the Victoria *Docks*, and in those of the London Docks; preparing it first in blocks and allowing it to harden before being used, as employed by Walker at the Dover Breakwater, and by Hawkshaw for the new sea forts for protecting the arsenals of Plymouth and Portsmouth; and depositing it in a liquid state and allowing it to set under water, as practised upon a gigantic scale by M. Noël, in the construction of the large Government Graving Docks at Toulon. In the latter case hydraulic concrete has been deposited in a liquid state in the sea water, at a depth of about 40 ft., forming a vast rectangular trough of béton about 100 ft. wide, of the length of each dock respectively, and with walls and bottom about 16 ft. thick. After the béton had set, the water was pumped out from the interior, an inner lining of masonry to form the altars, stairs, and floor was built, the caisson put into its place, and the concrete side of the trough at the entrance having been removed, the dock was complete.

The facilities for making béton or hydraulic concrete, which has the invaluable property of setting under water, and of thus forming an artificial rock or stone, are very great; as it may be formed either from the naturally hydraulic limes, the artificially hydraulic limes or cement, or from the rich or non-hydraulic limes, rendered hydraulic by the admixture of other substances, such as *pozzuolana*, minion, or iron-mine dust.

The beton made from the naturally hydraulic limes, which are found extensively in this and other countries, is the most to be depended upon. The blue lias in England, the limestone of Arden, found near Glasgow, and that of Theil in France, are good specimens of their kind, possessing in an eminent degree the property of setting under water. Of the Arden lime, the author and his partner have had abundant experience in the dock works at Glasgow, Greenock, and other places. As to the blue lias, its extensive employment in the docks at Liverpool, London, and other important works throughout the kingdom, is proof of its good properties. The hydraulic limes of France have been still more severely tested, by their application for the formation of the large concrete blocks used for the protection of the seaward side of the French breakwaters. It may be useful to mention, for comparison, the proportions of some of the concretes made from these various limes. The Arden lime concrete, employed by Bell and Miller for the foundations of the large Graving Dock at Glasgow, was composed of 1 part of ground Arden lime, 1 part of iron-mine dust, 1 part of sand, and 4½ parts of gravel and quarry chips. The lias concrete, used at the recent extension of the London Docks by Rendel, consisted of 1 part of blue lias lime to 6 parts of gravel and sand.

The proportions adopted for the blocks of the Mole at Marseilles, were 2 parts of broken stones to 1 of mortar, the latter being composed of 3 parts of Theil lime to 5 of sand.

A knowledge of the mode of composing artificial hydraulic limes is of great importance in situations where natural hydraulic limes are not easily procurable. Smeaton was the first to point out that it was to the clay or silicate of alumina in the composition of the hydraulic limes that they were indebted for their peculiar property. Subsequently the able researches of Vicat showed by actual experiment how all the rich or non-hydraulic limes might be rendered eminently hydraulic by burning them with a certain proportion of silicious clay. Indeed, to Vicat is due the credit of having reduced the knowledge of limes to a system, and of having shown the practical application of concrete as an eminently constructive material. The excellent artificial *cements* now manufactured are most valuable to the engineer; and the concrete made with Portland cement can hardly be surpassed. That used at the new Westminster Bridge is harder and more compact than the greater number of building stones, even where put down in the bed of the Thames, and where it is exposed to the running stream. Portland cement concrete is also extensively used for the artificial blocks, weighing from 6 tons to 10 tons each, which form the hearting of the breakwater at Dover and that at Alderney, the proportions being 1 part of cement to 10 parts of shingle.

Some substances, such as pozzuolana—a volcanic production found chiefly in Italy—have, in consequence apparently of silicate of alumina being predominant in their composition, the property of giving hydraulic qualities to the rich or non-hydraulic limes. It is of these that the concrete is made, which has long been used for marine works on the shores of the Mediterranean; and, indeed, the piers at some of the Italian ports have been constructed almost entirely of hydraulic concrete. Daniel Miller, the author of this paper, had an opportunity of examining at Genoa the extension of one of the moles of the harbour, the inner side of which has a vertical wall constructed under water entirely of pozzuolana concrete simply thrown into the sea from baskets carried on men's heads, a boarding confining it to the shape of the wall. In a short period it set quite hard, so as to enable the upper part of the wall, which is of stone, to be built upon it. The outer side of the mole, which had been previously made, was formed by stones deposited "à pierre perdue." Though the depth of the quay wall was not great, this shows the confidence which the Italian engineers have in concrete applied under water in a soft state. The piers of the new basin constructed by the Austrian Government at Pola, in Istria, are also formed, in a similar manner, of concrete confined between rows of timber piling.

Perhaps the most striking application on a large scale of pozzuolana concrete is in the great mole which protects the port of Algiers. To form the mole, blocks of béton of immense size, so as to be immovable by the force of the sea, were employed. Some of these were formed *in situ* by pouring the concrete into large timber cases without bottoms sunk in the sea in the line of the mole. Other blocks of a smaller size, though upwards of 30 tons in weight, were made on shore, being moulded in strong wooden boxes. After the béton had set, the boxes were removed, and the blocks were launched into the sea to find their own level. The béton for the blocks *in situ* was composed of 1 part of rich lime in paste, 2 parts of pozzuolana, and 4 parts of broken stone; that for the blocks made on shore was formed of 1 part of lime in paste, 1 part of pozzuolana, 1 part of sand, and 3 parts of broken stone. These blocks set sufficiently hard in twenty-four hours to resist the shocks of heavy seas, and the mole now stands firmly, instead of being, as it was when formed of loose blocks of stone in the time of the Moors, nearly destroyed every winter.

The French engineers have shown great boldness and skill in the application of béton, as exemplified in the Pont de l'Alma over the Seine, the arches of which, as well as the piers, are formed of rubble concrete; in the new Graving Dock at Toulon; and in the formation or protection of breakwaters by enormous artificial blocks of béton, as carried out at Marseilles, Cherbourg, La Ciotat, Cette, Vendres, Cassis, and Algiers. When Miller inspected the mole, or breakwater, which encloses the harbour of Marseilles, he found the huge rectangular concrete blocks, weighing upwards of 20 tons each, by which its seaward side is protected on the "pierre perdue" principle, perfectly entire and sharp in their outline, though they had been exposed for many years to the action of the sea. Anyone standing upon that mole, and witnessing in a gale the heavy seas breaking with tremendous force on these concrete masses and recoiling harmlessly, could have no doubt as to the efficiency of concrete as a constructive material.

Hydraulic concrete, to be effective, requires care and attention in its manipulation, and in the regulation of the proper proportions of its materials. Any failures must have arisen from inattention to these or similar points, as there is ample experience to show that, when properly made, every confidence may be placed in its strength and durability. Even where stone is abundant, this material may be often employed with economy and advantage; but where stone cannot be obtained, the importance of being able to form an effective substitute, out of materials of so little value, and so widely distributed, can hardly be overrated.

Construction of Dock and Quay Walls without Coffer-dams.—In sea water the engineer has to encounter enemies which do not exist in fresh water, or at least only to a trifling extent. The "teredo navalis" and other worms quickly destroy timber, and the corrosive action of the sea water, and other peculiar properties, have a prejudicial effect upon iron. In consequence of these deteriorating influences, these materials have not hitherto been much employed in sea works where durability is essential. There is no doubt, however, that they may be employed with advantage, if protected from the destructive action alluded to; and whatever materials may be used, it is desirable that the surfaces exposed to the sea should be of continuous stonework or other material capable of resisting its effects.

As Engineers-in-chief for the Albert Harbour at Greenock, D. Miller and his partner Bell have had an opportunity of introducing a new system for the construction of sea-walls and quays in deep water, without the aid of coffer-dams, by which a large saving is effected, and works of great solidity and durability have been secured.

The accommodation for the loading and discharging of the shipping of Greenock consists of three open tidal docks or harbours, the most recent having been constructed by Locke. Extensive schemes for wet docks have been proposed at different times by several engineers, particularly by Rennie, Telford, and Walker and Burges, but hitherto no wet docks have been constructed, as it has been considered that the moderate range of the tide—from 8 ft. to 10 ft.—does not render them indispensable, and the trade is found to be efficiently worked by the present system. In the additional accommodation the system of harbours is adhered to, though provision is left for conversion into wet docks by the addition of locks and gates, should this at some future period be deemed advisable.

The new works are situated on the west side of the town, and, in order not to interfere with valuable shore ground, they have been projected almost entirely beyond the high-water line into the sea. The depth of water at the outer line being considerable, the amount of excavation required in the interior is comparatively little. The outer sea pier, according to the plan proposed by the engineers, encloses a large extent of shore as well as the Bay of Quick, and when carried out to the full extent will be upwards of 3000 ft. in length. Within this area there is a space for two harbours, each 1000 ft. in length, 15 ft. deep at low water, or 25 ft. at high water, with entrances 100 ft. wide.

The depth of water along the line on which a coffer-dam must have been constructed, had such been contemplated, is in many places nearly 30 ft. at high water; and taking into account the length, and that it must have been of strength sufficient to resist the storms of winter, it could hardly have cost less than 50,000*l.* Besides the great cost of a coffer-dam, there was another difficulty, as, owing to the line of the proposed new pier being close to the edge of the deep-water channel, it would have been necessary to project the coffer-dam so far into the channel as to have formed a serious interruption to the traffic. In consequence of these difficulties, and from considerations of economy, it had been the intention of the trustees to use timber for the outer piers of the harbour, and the engineers were instructed to make their plans accordingly. It was the opinion, however, of Miller and his partner, that in a situation where the sea worm is very destructive, the work ought not to be constructed of such a perishable material, and that it was quite possible to build a solid structure, so as to avoid the difficulties referred to, in an economical manner. In order to effect this, they proposed to construct the outer pier and quays forming the seaward side of the dock without coffer-dams, so that the pier might itself serve as a coffer-dam for the interior operations in the harbour which would afterwards be required. The seaward pier is 60 ft. wide at the top, having quays on both sides.

The mode in which the work was designed was to form the walls under low water of a combination of cast-iron guide-piles in the front, with a continuous stone facing slid down over and enclosing these, and of concrete backing deposited in a soft state, all of which could be easily accomplished from above the water line. Timber bearing-piles were to be used in the body of the walls where required, and the upper part of the walls from the low-water line was to be carried up of masonry in the usual manner, Figs. 3876 to 3881.

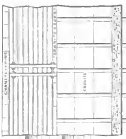
Granite from the Ross of Mull was substituted for freestone, for the stone facing under the low-water line, as it could be obtained in large blocks at a moderate price.

The first operation in the construction, when the water is not sufficiently deep, is to dredge out two parallel trenches to 17 ft. below low water, for the foundations of the walls. A staging of timber piles is afterwards erected in the line of the pier over the whole breadth, for carrying the tramways, travelling cranes, and piling engines. Cast-iron guide-piles are then driven from the staging, with great precision, 7 ft. apart, in the line of the face of each quay-wall. These piles are driven till their heads are near the low-water line, and they form guides for putting down the stone facing. They are connected at the top transversely by wrought-iron tie-rods stretching through the pier, cottered into sockets and binding the heads together. At first it was thought that there would be some difficulty in driving the iron guide-piles with the required exactitude, but this was overcome by pile engines of peculiar construction, devised by William York, one of the contractors, Figs. 3882, 3883. These travel on the rails of the scaffolding, and are furnished with long arms projecting downwards, strongly stayed by diagonals, and forming a trough, into which the pile is placed, and from which it is driven by the pile engine in the manner of an arrow from a cross-bow, being obliged to go down perfectly straight.

The ground is very unequal, the hard substratum, or red till, being in some places 20 ft. below the bottom of the wall, the upper strata being mud and soft sand. In such cases timber piling, driven to the same level as the iron piles, is used to form a platform for sustaining the part of the wall above low water; but where the ground is firm this is not required. When the proper depth has been dredged out and the piling driven, a bed of hydraulic concrete 3 ft. thick and 20 ft. wide is deposited in the trenches, to form a base for the wall to spring from, and to give a large bearing surface. Into the grooves formed by the flanges of the iron piles large granite slabs, from 18 in. to 2 ft. thick, are slipped, the bottom one resting upon a concrete base and on a projecting web cast on the piles: not more than three stones fill each compartment between the piles, 16 ft. in height and 7 ft. in width. These stones slip into their places with the greatest ease, and form the face of the wall under water. Behind this facing hydraulic concrete is lowered under the water in large boxes having movable bottoms, and is discharged in mass to form the body of the wall. To confine this at the back before it has set, loose rubble stones are deposited and carried up simultaneously with it. The hearting of the pier, consisting of hard till, stones, and gravel, is deposited afterwards, and the whole carried up to the level of low water.

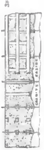
The entire mass, piles and stone facing, concrete backing and hearting, is allowed to consolidate for a sufficient time; after which the heads of the iron piles and the granite facing blocks are capped at the level of low water by a granite blocking or string course, and the upper portion of the walls is carried up in freestone, ashlar, and rubble. The remainder of the hearting between the walls is then filled in, and the whole is finished with a granite coping and causeway. The

3878.



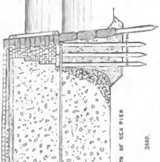
ELEVATION OF PART OF PIER

3881.



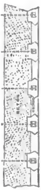
PLAN OF PART OF PIER AT LOW WATER

3877.



SECTION OF SEA PIER

3880.



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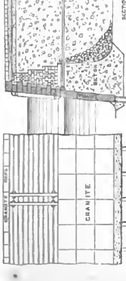
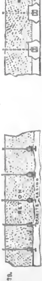


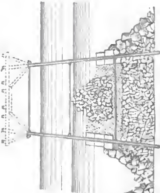
ELEVATION OF PART OF PIER

3879.



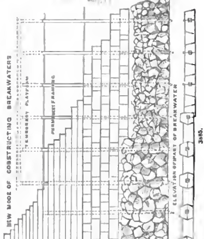
PLAN OF PART OF PIER AT LOW WATER

3886.



SECTION OF PERMANENT FRAMING AND TEMPORARY PLATFORM

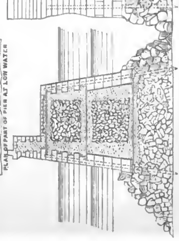
3885.



NEW MODE OF CONSTRUCTING BREAKWATERS

ELEVATION OF PART OF BREAKWATER

3884.



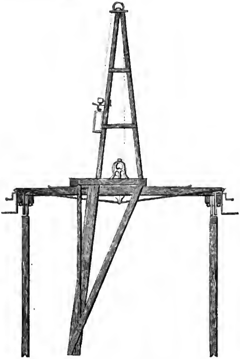
SECTION OF BREAKWATER WITH PARAPET

walls are 33 ft. in height from the foundations, 11½ ft. thick at the concrete base, and they diminish to 5 ft. thick at the top.

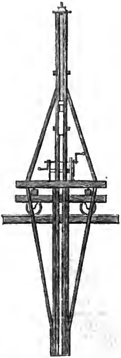
Particular care is taken with regard to the hydraulic lime. It is burnt at the quarries, but is brought from thence in the shell by the railway in covered wagons, so as to preserve it from wet. It is ground at the harbour works, for which purpose, and for mixing the mortar, there have been erected four vertical double-roller mills and two sieves, driven by an engine of 20 horse-power.

In the part of the pier which has been already executed, the stone facing under low water being made to slip into the groove formed by the flanges of the iron piles, the outer flange is left exposed to the action of the salt water, which no doubt will in the course of time exert an injurious effect upon the iron, Figs. 3878 and 3881. To remedy this, it is intended in the remainder of the work to reverse this plan, and to make the grooves in the stone facing, into which the outer iron piling will fit, Figs. 3876 and 3879. The stone blocks will therefore overlap the iron piles, and form a continuous stone facing, so that no part of the iron will be exposed to the action of the salt water. The grooves will be filled from the top with cement, which will enclose the iron flange, and effectually preserve it.

3882.



3883.



The concrete employed is formed of Arden hydraulic lime, iron-mine dust, sand, gravel, and stone chips—the lime and the mine dust being well ground, under edge stone mills, before being mixed with the other materials. The proportions are by measure—1 part of ground lime, half a part of mine dust, 1 part of sand, and 3 parts of gravel and stone chips. Immediately after being mixed, and when brought to a proper consistency with water, it is conveyed to where it is to be used, is let down under water in the discharging boxes, and in a short time sets very hard. The boxes used are either of iron or of wood, and contain 1 cub. yd. each. Those of iron are found to be preferable, as the buoyancy of the wooden ones renders them somewhat unmanageable in a tideway, after their contents have been discharged.

This mode of constructing walls in deep water without coffer-dams has proved very successful, and a sea pier of great solidity and durability has been formed at a comparatively moderate cost.

In constructing quay-walls on the foregoing principles, different modes of forming the stone casing may be employed; and particularly where stone of a softer nature than granite, such as limestone or freestone, is used, a still more efficient outer casing may be obtained, Fig. 3880. In it, blocks of stone, having orifices or holes cut in them, are strung or put down over the iron piles, so as completely to enclose them. These blocks have also grooves or projections on their sides, in which are slid down intermediate slabs or blocks of stone, having corresponding grooves or projections. A continuous facing of stone, having all the stones locked into each other, is thus formed, and the iron piling is effectually enclosed. It was on this principle that the facing under low water was intended to have been formed at Greenock, previous to its having been suggested to employ granite instead of freestone. Still further to protect the iron from the action of the salt water, the holes round the piles would be filled up from above with cement well rammed down, so as to fill up all the joints, and to unite the stone and iron together. This plan admits of the iron piles being kept farther apart than when single blocks connect the piles. Concrete backing may then be filled in, and the structure be completed as previously described. Temporary sheet piling or boarding, instead of loose stone, may be employed to keep the concrete in its place until it has set. In many cases, blocks of béton, which can be easily moulded into the shapes required, may be advantageously substituted for stone in the facing, as it has been proved by experience that, when properly made, they possess the requisite strength and durability.

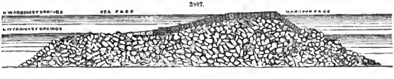
The range of different purposes to which this system of founding marine structures is applicable is very extensive, and works such as the formation, re-facing, or reconstruction of quay-walls; the formation of docks or tidal basins on sites covered by the sea; embankment walls along the shores of seas or rivers; the foundations of lighthouses, beacons, or forts which may require to be made in the sea; the construction of breakwaters enclosing harbours of refuge; may be effected with a speed, facility, and economy not hitherto attainable.

Although various Royal Commissions and Parliamentary Committees have elicited much valuable information on this subject, the main object of diminishing the enormous cost of these works, and of providing a durable and substantial, and at the same time economical, barrier to the force of the sea, is as yet a desideratum. So important, indeed, has this become, that in 1860 a Select Committee of the House of Lords was appointed to inquire, how far it might be practicable to adopt some plan, for the construction of breakwaters and harbours of refuge, less costly than the system of solid masonry then in use. Various plans were discussed, and amongst them floating breakwaters; but the investigation failed to establish any effectual substitute for the present mode of construction.

The plans about to be described will, in our opinion, have a material effect in filling up this want. Before proceeding, however, it will be necessary to refer briefly to the principal modes of construction hitherto adopted, and to consider the peculiar phenomena by which such structures are affected.

The most common mode of forming breakwaters is the "pierre perdue," or long-slope system. This is simply the deposit in the sea of a vast amount of loose rubble stone, rising to about the level of high water, allowing it to take its own level, and to be acted upon by the sea until its section assumes the permanent form which this action gives it. The seaward side obeys the laws of ordinary sea beaches, and forms itself into a long sloping shore, involving the employment of an enormous amount of material before the mound reaches the height to give the required protection. Such a system is only applicable where stone is abundant, and can consequently be deposited at a cheap rate. Of this system the Plymouth, Cherbourg, and Holyhead breakwaters may be taken as examples, Figs. 3887, 3888.

3887.



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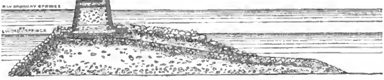


In situations where stone is not abundant, the opposite principle, called the vertical system, is adopted. In this mode the walls are built upright from the bottom; and as all the material below low water is put in place by diving apparatus, and is of an expensive nature, the cost of a work executed in this way is very great. The Dover Breakwater, in course of construction, is the most prominent example. It is built up solid from the bottom of the sea, the exterior facing being of ashlar granite blocks robated, or checked into each other, and the hearting of rectangular blocks of concrete, built in the same way as ashlar masonry up to the level of high water, above which it is filled in with liquid concrete, Fig. 3875.

Besides these systems, which may be taken as the extremes, an intermediate form of section, combining both to a certain extent, is adopted. It consists in carrying up a rubble mound to within a certain depth below low water, and upon this building the remainder of a vertical construction. The Alderney Breakwater may be taken as representing this system to a partial extent, Fig. 3894.

It has been a subject of discussion as to whether the long slope or the vertical wall was the better section for breakwaters, and as to the relative force of the sea exerted upon them. The observations which have been made on waves may be said to have settled this point in favour of vertical walls, as it has been clearly shown that waves in deep water are chiefly oscillatory in their character, the fluid having little progressive motion in itself, and consequently exerting but little force on objects opposed to it; but in shallow water waves assume an entirely different character, as they acquire a progressive motion, becoming waves of translation, in which the fluid is carried bodily forward in a horizontal direction, and in consequence it strikes any body opposed to it with great percussive force. Vertical walls, therefore, which rise from the deep water, being only subject to the oscillatory movement of the waves, are least exposed to the destructive effects of storms. The evidence taken before the Royal Commission in 1859 seemed to be conclusive on this point; and the opinions of the Commissioners, as developed in their report, may be considered to have set this subject at rest. But whatever difference of opinion there may still be upon this matter, there can be no question as to the vast saving of material by vertical walls, and of the great economy which would result, provided a simple and easy mode of construction could be adopted. The vertical system has, besides, the great advantage of being applicable in many cases as quays for vessels lying alongside to load and discharge, which may be turned to valuable account both for commercial purposes, and in times of war, for the rapid shipment or debarkation of troops, stores, and other material.

The experience, however, derived from the formation of the great breakwaters on the "pierre perdue" or long-slope principle, such as Plymouth, has been very valuable. The examination of the sections which the materials assume, shows that the great disturbing action of the sea, or conversion of the waves of oscillation into those of translation, does not extend to any considerable depth; as it is found that the long sloping beach terminates generally at from 12 ft. to 15 ft. below low water, after which the inclination becomes much steeper, the materials assuming nearly the form due merely to the natural angle of repose, as if unacted upon by any force except that of gravity. The inclination on the seaward side within the tidal range, and to the depth of 12 ft. or 15 ft. below low water, is generally 5 or 6 horizontal to 1 vertical, but below that depth it is only from 1 to 1½ horizontal to 1 vertical. It is the long slope which these breakwaters assume to a certain depth, that causes the enormous absorption of material; but it appears that a mound of rubble may be deposited to within a certain distance of low water which will not have this long slope, and consequently will only require a comparatively small quantity of material. The consideration of these facts shows that in the generality of cases, the vertical and "pierre perdue" systems may be combined with advantage and economy, by first depositing a rubble mound to about 15 ft. below low water, and from that point carrying up the remainder of the breakwater by vertical walls.

A great improvement in the facility of constructing these breakwaters, when such an immense quantity of material has to be deposited, was the introduction by Rendel of timber staging carried on piles in advance of the work, and sustaining lines of rails, by which the material can be brought down and be deposited in the sea with a rapidity before unattainable. The consumption of timber is, no doubt, very great, as much has to be left imbedded in the work, and there is considerable destruction besides; but this is amply compensated by other advantages. By this system an average of about a million tons of stone a year have been deposited at Holyhead, and a similar plan is pursued at Portland, Fig. 3893.

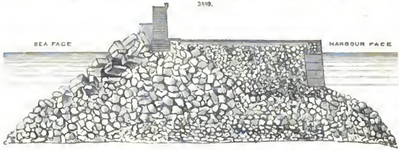
Massive staging is also employed at the vertical breakwater at Dover, for facilitating the building operations. Indeed, staging may now be considered essential in the generality of cases for the economical construction of such works.

The breakwaters of the French engineers are generally formed "à pierre perdue," but upon a different method from that pursued in this country. Thus, at the Plymouth Breakwater, Fig. 3887, only large blocks of rubble stone were deposited, the small being thrown aside, and at Holyhead and Portland, the large and the small rubble were deposited promiscuously; while the French engineers usually employ the small rubble for the core, and reserve the larger blocks for the outer coating. Furthermore, they protect the seaward side by blocks of béton, thrown in to take their own position, and of such a size (generally from 20 tons to 30 tons) as effectually to resist displacement by the utmost force of the waves. These blocks assume a slope as steep as 1 to 1 under the water line, so that the mass of material in a breakwater thus constructed, is considerably less than where smaller materials are employed for the seaward face. The moles of La Joliette and Napoleon which enclose the harbour of Marseilles, are excellent examples of this mode of construction, Fig. 3889.

Having thus glanced at the general principles which affect breakwaters, and described the modes of construction usually adopted, the conclusion to be arrived at appears to be, that the vertical system is that which best resists, or rather averts, the destructive action of the sea, and requires the smallest amount of material. However, both systems, the long slope and the vertical, as at present carried out, are very expensive, the former from the quantity of material which is required, the latter from the costliness of the material and the mode of construction. The one system may be characterized as involving the maximum in quantity, and the minimum in cost of material; the other, on the contrary, the minimum in quantity and the maximum in cost of material. The object sought to be attained by the system about to be described is to effect a minimum, as far as possible, both in the quantity and in the cost of the material.

According to circumstances, breakwaters on this system would be constructed either wholly vertical, extending from the bottom, or partially vertical, springing from a rubble mound. For the sake of comparison, the mode proposed by Daniel Miller, Figs. 3884 to 3886, is designed to suit the conditions usually prevailing; say a range of tide of 15 ft., and a depth at low water of 6 fathoms, being about the same as at the Plymouth Breakwater, and as at Hartlepool, Filey Bay, and the entrance of the Tyne, where the most important harbours of refuge have been recommended by the Royal Commissioners. The section, Fig. 3891, represents a breakwater with a parapet, but this is not indispensable to the main object of a breakwater, and is only required in certain cases, as where the inner side is to be used for commercial purposes. Where the parapet can be dispensed with, the top of the breakwater may be capped by large blocks of beton, or stone, of such a weight as not to be displaced by the heaviest seas, Fig. 3890.

3889.



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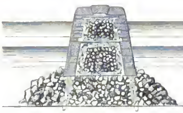

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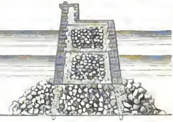
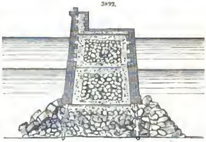


The principal feature of the new plan is a framework of iron, formed of piles or standards, and ties, which serves as the staging for all the constructive operations, and afterwards becomes an essential portion of the structure, by binding together a strong casing of stone or other sufficiently durable material, which encloses and forms the facing of the breakwater, allowing the interior to be filled up with loose rubble or other cheap materials, which may be cemented into a solid mass by means of liquid beton or concrete. It will be preferable for breakwaters to make the standards of wrought iron, and in the generality of cases it will not be necessary to drive them into the ground, but simply to set them in place.

3892.



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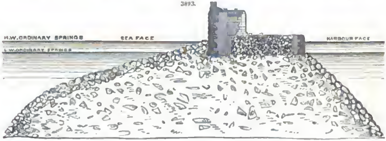
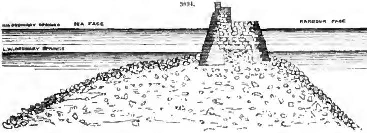


The mode of proceeding is to erect the iron staging in advance of the work, which may be done either by driving, screwing, or guiding the piles, or standards, from a machine placed on the platform, and travelling along as it progresses. This machine will have long guides firmly stayed and set accurately in position, into which the iron piles will be placed, and then driven in a similar manner to that pursued at Greenock. When two piles are erected in place, they are connected transversely by iron ties, and by the temporary platform at the top for bearing the rails, and the piling machine is then moved on to drive the next set, and so on. Following this operation come the wagons depositing the material to form the rubble mound, which collecting round the lower part of the standards, firmly fix them in their places, and give stability to the staging. When the mound has risen to the required height, say 18 ft. below low water, the cranes from the staging above commence lowering the casing blocks for the facework. These are made to enclose the iron standards, and are formed so as to be arched or locked into each other, and thus to resist any pressure arising from the backing. They can be made to break bond, or to slide down without breaking bond, as may be considered desirable; but the former plan permits the standards to be kept at a greater distance apart, and the blocks to be of less dimensions, and at the same time of greater strength.

3894.



Simultaneously with the building of the casing, the hearting of the work, rough rubble or other suitable material, is to be deposited from the wagons on the staging, filling in from the centre, while backing of béton, or hydraulic concrete, will be lowered down in large boxes, and discharged behind the stone casing, consolidating and cementing together the rubble hearting, as it is filled in and falls down.

It will be observed that the whole of the facing is rendered continuous, and by all the blocks being arched, or grooved into each other, it is impossible that any individual block can get out of place. This is a danger greatly to be feared in structures of this kind built in the ordinary way, as the action of the compression of the air in the joints of the masonry, by the pressure of the waves, and the after-expansion when the waves retire, is sometimes so great as to blow out the stones, thereby endangering the whole structure.

By this system great solidity and strength may be obtained, as the whole structure is bound firmly together by the iron framework; while the manner in which the stones of the facing are locked into each other, and in which the concrete will penetrate and solidify in a short time the whole mass, will realize as nearly as possible the idea, which should be the object of attainment in such structures, of a monolith, or solid rock in the bed of the ocean.

The blocks forming the casing under water may be either of stone or of béton. When the former cannot be conveniently procured, the latter may be used with advantage, particularly as it can be so easily moulded into the required shapes, and almost of any size. The power of such blocks to resist the action of the sea for an indefinite period is now fully confirmed. These may at least be generally adopted for the inner walls of breakwaters. Indeed concrete blocks, built in the ordinary way, have been already used by Walker and Burges at Alderney, Fig. 3894, for the inner facing.

The great economy of this system of constructing breakwaters would arise from the smallness in quantity and the cheapness of the bulk of the material. The quantity of material in this breakwater compared with that in the Plymouth Breakwater on the long-slope principle, in the same depth of water will be about as 1 to 4, and the disparity of cost is not less striking, the Plymouth Breakwater having cost nearly 900*l*. the lineal yard.

In comparing with any other mode of construction, the iron framework may be allowed to go for nothing, as staging of some kind must be used for the speedy and economical construction of any kind of breakwater. This framework of iron standards will not cost more than timber staging, and, indeed, far less than in cases where an immense quantity of staging requires to be used for the deposit of the enormous mass of material of long-slope breakwaters, such as at Holyhead; while it will be far more secure, in consequence of its inherent strength, the heavy nature of the material, and the small surface presented to the action of the waves. The buoyancy of timber staging is an element which causes its own destruction, as is exemplified at Holyhead, where it is admitted that for every piece of timber another piece is required to make up for the loss.

Another important advantage is the great speed with which it may be constructed, from the mass of the material being of a nature easily deposited, and from the facility with which operations may be carried on upon a long stretch of the work at one time. In situations where the materials for the construction of ordinary breakwaters cannot be obtained, the advantages of this system would be still more striking. Dover may be taken as an example, there being no stone in the neighbourhood suitable for depositing "à pierre perdue," or building vertically in the usual modes of construction. By the system proposed the harder chalk from the cliffs and shingle could be used for the hearting, as in a structure so firmly bound together these materials concreted with béton would serve the purpose quite as well as any other. In forming the rubble mound the example of the French engineers might be followed with advantage by forming the core of smaller and inferior materials, and for this the chalk and shingle would be quite suitable. This would be protected by a thick layer of rubble, and on the seaward side by a layer of concrete blocks, of such a size as would not be disturbed by the sea. The vertical superstructure would be constructed of chalk or sandstone rubble, concreted by béton for the hearting. A breakwater upon this construction, Fig. 3892, Miller estimates could be built at Dover for 290*l.* per lineal yard. The present breakwater for the same depth of 45 ft. at low water is contracted for at 1245*l.* per lineal yard, so that there would be the enormous saving of upwards of one million and a half sterling per mile. The difference in the cost of construction, vast as it is by this system, is not the whole saving, as the time occupied is an important element, affecting the final cost of such a work, the interest on the outlay being lost until the harbour becomes available. There can be no doubt of the solidity and durability of the Dover Breakwater, but considering its enormous cost, and the distance into the future before its completion will render it available for commercial or for war purposes, the wisdom of prosecuting it upon the present mode of construction may be well called in question. Upon the construction proposed the breakwater could be completed and be available as a harbour of refuge for the naval and commercial fleets of the country in less than five years, at a cost of little over 1,000,000*l.*

Breakwaters and piers have been frequently made of timber framing and casing, confining a mass of rubble. Extensive piers on this principle are in existence in Boulogne, Calais, Dunkirk, and other ports; but it is evident that such a system, from the timber being exposed and the consequent want of durability, and from their liability to sudden destruction when once the casing gives way, must prove very expensive in the end. This system has been revived, though upon more scientific principles, by Abernethy and Michael Scott. In these plans a structure composed of a casing of timber is formed of timber frames, standards, or piles and planking, and this casing is afterwards filled with rubble. But as the casing cannot be expected to possess much durability, it is proposed subsequently to enclose this structure by solid walls of masonry or composite blocks, for which the first structure will afford a convenient and substantial platform for bearing the rails and cranes necessary for executing this part of the work. There are two distinct operations necessary, therefore, to complete the work upon this mode in a permanent manner; first, the formation of the inner structure with its timber casing; and, second, the formation of the outer structure, for the purpose of making a casing of a durable character. The economy of making breakwaters of a durable construction on these modes has not been fully made out, chiefly arising from the great quantity of timber required and the necessity of employing two distinct casings, one of which must be superfluous.

The system which Miller has proposed will, we think, secure all the objects which appear to have been aimed at by these plans, but with greater simplicity and economy.

It is not essential that the standards employed in the system proposed by Miller should be of iron, as they may be of timber, but enclosed, as has been already described in the case of iron standards, in a casing of blocks of stone or of béton.

See BARRAGE. BRIDGE. CANAL. CEMENT. COAST DEFENCES. CONSTRUCTION. DAMMING. DOCK. HYDRAULICS. LOCKS AND LOCK-GATES. WEIRS.

HAULAGE. FR., *Roulage*; GER., *Förderung*; ITAL., *Estrazione e trasporto del litantrace*; SPAN., *Arrastre.*

Haulage of Coal, taken from the Report of the Committee of N. E. I. M. Engineers, 1869.

Tail-Rope System, North Hetton Colliery, County of Durham.—In order to give an idea of the extent to which the tail-rope system can be applied in leading coals underground along an engine-plane with numerous curves and branches, the following description is given of the arrangement of wagon-way, and the method of working the tail rope, at North Hetton Colliery, which affords the best example of this system.

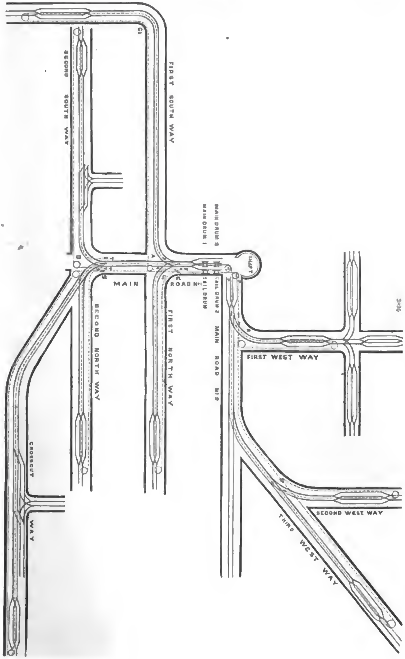
Fig. 3895 shows that there are two main wagon-roads in this pit, lying at right angles to each other—No. 1 plane being driven east, and No. 2 north. The following are the particulars of the engine and wagon-way;—

ENGINE.	
No. of cylinders	2
Diameter of cylinders	12 in.
Length of stroke	24 „
No. of drums	4
Diameter of drums	4 ft.
Size of rope (circumference)	2½ in.
The boilers are on the surface.	

ENGINE-PLANE.		
Rails	22 lbs. the yd.	
Gauge of way	2 ft. 4 in.	
	Main.	Tail.
Rollers.—Diameter	5 in.	8½ in.
Weight	26 lbs.	32 lbs.
Distance apart	21 ft.	21 ft.
Sheaves at curves .. diam.		10½ in.
Tail sheaves	4 ft.	

When the ratio of the diameters of the pinion to the spur-wheel was as 1 to 2, the engine was found rather too weak for its work, and the ratio was therefore made as 1 to 3. The engine goes at a speed varying from 150 to 250 strokes a minute, the usual speed being about 180 strokes a minute. This makes the power exerted to be about 100 horse-power, and thus presents an example, which is rare, of a tail-rope engine working to the utmost of its power.

One end of the shaft of each set of drums is placed on a movable carriage, by means of which they are put into gear with the driving pinion. The drums are connected to the shaft by means of clutch gear. The engine and drums are placed beneath the wagon-way, and the wheels W and W^1 which direct the course of the ropes for No. 2 plane, as well as several other 4-ft. wheels upon


FIRST SOUTH WAY
SECOND SOUTH WAY
MAIN DRUM 2
MAIN DRUM 1
SHAFT
MAIN
ROAD No1
TAIL DRUM
TAIL DRUM 2
SECOND NORTH WAY
FIRST NORTH WAY
MAIN ROAD No2
FIRST WEST WAY
SECOND WEST WAY
THIRD WEST WAY
CROSSCUT
WAY
3406

these planes, are also placed under the way. The ropes for the No. 2 plane come to the surface of the wagon-way about the point P.

No. 1 Plane.

	Ways.				
	1st North. yds.	2nd North. yds.	X-Cut. yds.	1st South. yds.	2nd South. yds.
Distance from shaft	900	870	1350	1000	825
Rise or fall from shaft	fall.	fall.	fall.	fall.	fall.
	min.	min.	min.	min.	min.
Time from leaving the shaft to returning	10	9	8	10½	9½
Heaviest gradient rising outbye	1 in 10½ for each way.				
Tubs in set	21 for each way.				
Speed of set	About 10 miles an hour.				

It may be observed that none of the branches are of very great length, and that all the ways rise towards the shaft.

No. 2 Plane.

	Ways.		
	1st West. yds.	2nd West. yds.	3rd West. yds.
Distance from shaft	580	1130	1200
Rise or fall from shaft	rise.	rise.	rise.
	min.	min.	min.
Time from leaving the shaft to returning	6	15	17
Heaviest gradient rising outbye	1 in 15	1 in 15	1 in 15
Tubs in set	35	35	35
Speed of set	About 10 miles an hour.		

No. 1 plane consists of a main road, with two branches on each side; at the end of the main road is another way, which, after going in a cross-cut direction for a short distance, turns to the north. These five branches are all worked by two of the drums, the other two drums working No. 2 plane and its branches. On the plan (which is drawn to no scale, and is therefore in many places out of proportion, owing to the difficulty in showing clearly the arrangement of rails) the ropes are shown by dotted lines. In the second west way and the cross-cut way there are two stations; a description of the arrangement of which is given hereafter. The four curves leading from the main way to the branches each have a radius of about 22 yds.; the radius of the curve in the first south way is 4 chains, and of that in the cross-cut way about 5 chains.

No. 2 plane has one main road and three branches, two to the west and the other in a cross-cut direction. The curves to the branches are about 3 chains radius, and the curve upon the main road about 4 chains.

At the far end of each of the branches there is a siding, one way for the full end the other for the empty tubs.

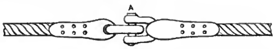
At the inbye end of the first west way there are three putting stations, from which the tubs are led in short sets by ponies to the siding at the end of the engine-plane.

The full way of the shaft siding is raised several feet to form a kep, or incline; and when the set of full tubs has been drawn on to the top of the kep, the tubs are let down to the shaft as they are required.

Arrangement of Ropes.—In the working of this and all other tail-rope planes, two ropes are necessary, which are called main and tail ropes, the former being used for drawing the set of full tubs outbye, and the latter for taking the empty set inbye. When the main rope is bringing the full set outbye, the tail-rope drum runs loosely upon the shaft, and by applying the brake the tail rope is made to run steadily off the drum; when the tail rope is taking the empty set inbye, the main-rope drum is put out of gear, and the main rope is drawn inbye behind the set. It will be seen on the plan of this engine-plane that the ropes for No. 1 plane have a direct lead from the drums, whilst those for the No. 2 plane are taken round pulleys at a right angle not far from the engine.

On No. 1 plane the ropes connected to the engine are those of the cross-cut way, and the set is supposed to have just arrived at the shaft; thus the main rope is nearly all wound upon the drum. At the points A and B, Fig. 3896, there are shackle-joints on both the main and tail ropes. The shackle used is of this description, and is secured by the pin A.

3896.

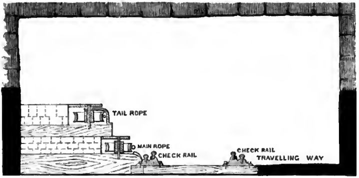


When the rope ends to which the set is attached are at the shaft, these joints are always at the points A and B, no matter from which way the last set came.

Most of the sheaves used in taking the ropes round the curves are fixed horizontally in walling built for the purpose, exhibited in Fig. 3897.

At C and C both the ropes are taken round the curves by small sheaves, as shown in sketch; but at most of the curves only one rope goes round the curve, the tail rope passing round a 4-ft. sheave; this arrangement is much to be preferred.

3897



Both main and tail ropes are 2½ in. in circumference. The large sheaves at the curves, and the tail sheaves at the inbye end of each of the branches, are 4 ft. in diameter; these wheels are placed under the way, and the rails are laid over them. Where the ropes are shown to cross the wagon-way on the plan, they are arranged to pass under the road.

The total length of main rope on the plane is 2520 yds., and of tail rope 9636 yds.; and there are altogether 1390 small sheaves, and 14 4-ft. sheaves upon the planes.

Method of Working the Planes.—No. 1 Plane.—On referring to Fig. 3895, it will be seen that the ropes connected to the engine are those of the cross-cut way, and that the ends of all the other branch ropes are lying at the branch ends. Supposing that the next empty set has to go into the second south way, whilst the rope ends at the shaft are being disconnected from the full set and attached to the empty set, the boy attending the switches at B is disconnecting the shackles S S and connecting them to T T; this is done in about two minutes, and is generally finished before the set at the shaft is ready to come away; the boy then opens the switches for the second south way, and everything is ready for the set going in. The set of empty tubs is taken into the branch, and the full set returns to the shaft before the ropes are altered again. Should the first north way next be ready the ends E E are replaced by F F, the switches are put right, and the empty set goes in and the full set comes out. If the cross-cut way be next ready, it will be seen that, to put the ropes right for this way, four rope ends will have to be connected, two at the station A, and two at B.

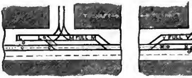
No. 2 Plane.—It will be seen, Fig. 3895, that the ropes connected to the engine are those of the third west way, and here also the set is supposed to be at the shaft. All the branches on the plane No. 1 are to the dip; on the contrary, all the branches from the main road on No. 2 plane are to the rise from the shaft.

The branch ropes on the No. 2 plane are connected in the same way as on No. 1 plane, and here also it is necessary to connect four rope ends when the third west way has to be worked, if the second and then the first west way have been worked before it.

In the first west way on No. 2 plane there is an adaptation of the tail rope which is worthy of notice. The gradient of this way is found heavy enough to cause the outcoming full tubs to pull the tail rope after them. In taking the empty set inbye the main rope is knocked off at the point R, and the set is pulled in by the tail rope; the full set is afterwards let down the incline by the single tail rope to R, at which point the main rope, which is necessary to pull the set on to the kep, is attached. The drum man sometimes brings the set out of this way by the brake whilst the engine is working another way. The gradient on the second west way is not heavy enough to allow this method to be adopted.

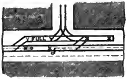
On the No. 1 plane there are two stations by the side of the main way, to which sets are taken several times during the day. One of these stations is in the cross-cut way and the other is in the second south way. When a set is intended for the station in the latter way, it is taken to L L, Fig. 3898, and there the ropes are knocked off; the full set stands at M M, and in order to get the ropes to this point, a piece of rope, the length of the set, is attached to the two ends, which are then pulled by the engine opposite to the ends of the full set. Thus eight connections and disconnections are necessary for each set led from this station.

3898.



Station on Second South Way.

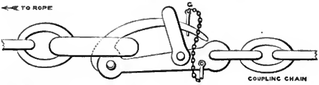
3899.



Station on Cross-cut Way.

The arrangement of the station on the cross-cut way, which was made some time after the station just described, is much better. Here, Fig. 3899, the way from X to Z is made to dip gently inbye, and when the empty set is brought inbye both rope ends are knocked off at X X, and the set runs forward by itself to Z Z; the ropes are then connected to the full set standing at Y Y.

3900.



The ropes are connected to the set by means of the link, Fig. 3900. The fastening is secured by a cotter, C.

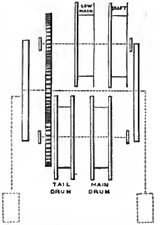
Duration of Ropes.—It is not known how long the ropes last, as a rope is first a main and then a tail rope, and is afterwards used as a tail rope on a lighter plane. The general duration of the rope is supposed to be from two to three years.

Londonderry Seaham Colliery, near Sunderland.—The engine-plane at Seaham Colliery is 2904 yds. long, the average gradient being a rise towards the shaft of 1 in 64. There are two stations by the side of the main way from which coals are led.

The engine, Fig. 3901, is horizontal, and has two cylinders. The drums are 6 ft. in diameter; they are at right angles to the wagon-way, and the ropes are taken round the turn by 4-ft. sheaves. Besides the drums used for the main engine-plane, there are two others, one of which hauls the tubs from the workings in the low-main seam to the shaft, and the other is used for taking the full set down from the bankhead to the shaft. Each pair of drums is connected with the engine by a movable carriage, the single drums being put in and out of gear as required by a clutch.

There are two boilers underground, at some distance from the engine.

3901.



Dimensions of Engine, Boilers, and Ropes.

Engine erected 1856.				
Number of cylinders	2			
	ft.	in.		
Diameter of cylinders	0	18		
Length of stroke	3	0		
Diameter of piston-rod	0	2½		
Length of connecting rod	8	8		
	in.	in.		
Dimensions of steam-ports	12⅞ × 1⅜			
" exhaust "	12⅞ × 1⅞			
	Steam.	Exhaust.		
	ft.	ft.		
Length of breech-pipe	6	10		
" main pipe	710	740		
	in.	in.		
Diameter of breech-pipe	5	6½		
" main pipe	6½	7		
	ft.	in.		
Diameter of driving pinion	3	0		
" followers	6	0		
" fly-wheels (2)	10	0		
	Main.		Tail.	
	ft.	in.	ft.	in.
Diameter of drums	6	0	6	0
" " including flanges	8	6	8	6
Width between flanges ..	1	6	1	6
Width of brake	0	4	0	4
Distance between centres of cylinders	13	6		
Boilers .. Number	2			
Description ..	Ordinary egg-ended			
	ft.	in.		
Length over all	33	0		
Diameter	5	10		

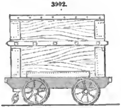
Boilers ..	Area of heating surface ..	each 220 sq. ft.	
	" fire-grate ..	" 20 "	
		ft. in.	
Receiver ..	Length	10 0	
	Diameter	3 0	
		Main.	Tail.
		yds.	yds.
Ropes ..	Length	2900	5800
		in.	in.
	Circumference	2¾	2½
		cwts. qrs. lbs.	cwts. qrs. lbs.
	Weight ..	76 3 14	138 0 0
		months.	months.
	General duration	8	12
Sheaves ..	Number	340	340
		lbs.	lbs.
	Weight	26	37
		in.	in.
	Diameter ..	6½	10½
		ft.	ft.
	Distance apart	24	24
			lbs.
	Return sheave, weight		.. 1428
			ft.
	" " diameter ..		8
			lbs.
Rails ..	Weight a yard		18
			ft. in.
	Length of each		12 0
	Gauge of way		2 0
	Rails laid on battens (6½ in. by 2½ in.), secured by sleepers spiked to them underneath.		

DIMENSIONS OF ENGINE, BOILERS, AND ROPES—*continued.*

Tubs, Fig. 3902; there are two sizes of tubs used indiscriminately at this pit.

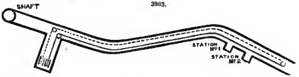
		Small tub.
	ft. in.	ft. in.
Length (inside)	3 3½	3 0
Breadth "	2 7	2 7
Depth "	2 4	2 5
Height above rails	3 7	3 5
Distance coupled	1 6	1 6
Diameter of wheel	0 12	0 10½
	lbs.	lbs.
Average weight (empty)	616	514
" coal contained	1008	916
Total number in pit	262	158
Number required to work engine-plane	260	

3902.



Description of Plane.—The bridge rails on the engine-plane are laid on battens. There are two short curves on the plane, Fig. 3903, one of which is 7 chains radius. The gradient is a general dip inbye, the heaviest gradient being 1 in 23.

3903.



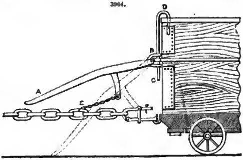
At each station there are two sidings, with a main way between; the tubs are taken into the branch ways over the main way by movable rails.

The sheaves for the main and tail rope are placed 24 ft. apart; the tail sheaves are all set between upright battens, about 3 ft. from the ground.

Description of Method of Working Plane.—The full set, generally consisting of 65 tubs, is drawn outbye from the station to which the empty set was last taken, by the main rope, the tail rope being attached to the other end of the set; when it has reached the kep at the bankhead, these ropes are knocked off, and the set is run down an incline a distance of 450 yds. to the shaft by a separate rope, which draws the empty set up to the bankhead; the tail-rope drum is then put into gear, and the empty set is drawn inbye by the tail rope.

The rope is attached to the fore end of the set by an ordinary hook, but at the other end, the application shown below is used when the set is coming outbye, to prevent the set running amain should the main rope happen to break. The iron cow A B, Fig. 3904, is secured to the bar at B by a pin C D, which hangs over the top of the tub; the short chain on the arm of the cow is hooked on to the main chain at E; when this chain is tightened, the pressure upon the short chain raises the cow, and prevents it from striking the rollers. If the main rope should break, the chain attached to the tail rope slackens, and the cow falls and keeps the set from running back.

3904.



Experiments with Dynamometer.—Before any experiments were made with the *dynamometer*, it was tested by placing it in a hanging position, and attaching various weights to it. The readings were found to agree with the weights applied. The dynamometer experiments are, in the opinion of the committee, unsatisfactory; and the comparisons which have been attempted to reconcile the results, have not yet afforded sufficient data for the committee to draw any reliable conclusions. The committee, therefore, feeling that this subject requires considerably more attention, hope that some member of the Institute will take it up where they have left it. The committee record the observations only, and the mode in which they were taken.

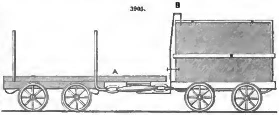
The experiments with this instrument show the traction, in cwts., required to overcome the resistance of the load upon the engine-plane, the readings being taken at the particular points indicated.

In the experiments at Seaham Colliery the *dynamometer* was applied as shown in Figs. 3905, 3906.

The plank A is prolonged on one side to act as a buffer, to prevent too much slackening of the instrument.

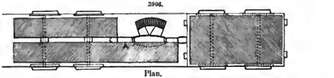
B is an iron crook fixed to an empty tub and made to fit the underside of the dynamometer to support it when slack. After a few trials it was found practicable to work without the crook—the strain keeping the instrument in its proper position.

3905.



Side view.

3906.

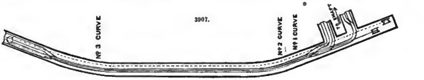


Plan.

The observer, lying on the tram, watched the needle continually, and noted down the readings at the points at which indicator diagrams were taken. See Dynamometer Car.

Seaton Delaval Colliery.—The engine-plane at Seaton Delaval Colliery is 2059 yds. in length, and is nearly level, having an average gradient of 1 in 643, dipping outbye. All the coals are led from the inbye end of the plane, there being no intermediate stations, Fig. 3907.

3907.

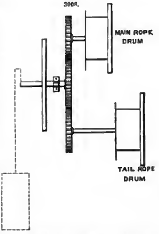


The engine, Fig. 3908, by which the plane is worked, is a single-cylinder horizontal engine, and the main and tail drums are on different shafts; the pinion and spur-wheels are of the same size, and thus the drum makes one revolution for each stroke of the engine. The diameter of the cylinder is 28 in., the length of the stroke 6 ft., and the diameter of the drums 6 ft., the main-rope drum being covered with a coating of hemp rope, making it 6 ft. 2 in. The ropes have a direct lead from the drums to the commencement of the plane, the distance from the engine to the point from which the set starts being 231 yds. The engine, during the day, hauls the coal and pumps water into the boilers, and at night pumps into the boilers. There are four boilers close to the engine, only three of which are in use at the same time.

This plane has been worked by engine-power rather more than twenty years. About 480 tons a day are now led, whilst formerly as many as 1300 tons have been led in one day—the average quantity being then 1100 tons a day.

The main rope originally was 3½ in., and the tail rope 3 in. in circumference; the ropes are generally replaced by pieces, and as they are not particular about always using the 3½-in. rope for main rope, the quantity of this rope is constantly varying; at present there is only 1400 yds. of it upon this plane.

3908.



DIMENSIONS OF ENGINE, BOILERS, AND ROPES.

	ft.	in.
Diameter of cylinder	2	4
Length of stroke	6	0
Diameter of piston-rod (passes through cylinder)	0	5¾
Length of connecting rod	11	1
	in.	in.
Dimensions of steam-ports	2½ × 12	
" " exhaust "	3½ × 12	
	Steam. ft.	Exhaust. ft.
Length of main pipe	93	100
	in.	in.
Diameter of main pipe	7½	7
	ft.	in.
Diameter of driving pinion	6	0
" " followers	6	0
" " fly-wheel (1)	15	0

	Main. ft.	Main. in.	Tail. ft.	Tail. in.
Diameter of drums	6	2	6	0
" " including flanges	11	0	11	0
Width between flanges ..	3	6	3	6
Width of brake	0	5	0	5

Cylinders, boilers, and pipes not covered.

Boilers ..	Number	4, 3 in use
	Description ..	Ordinary egg-ended
	Area of heating surface	each 108 sq. ft.
	Area of fire-grate ..	22·5 "

		ft. in.	ft. in.
Boilers ..	Length over all	2 at 30 0	2 at 25 0
	Diameter ..	2 " 5 6	2 " 6 0
	Water evaporated in 12 hours	1578 cub. ft.	

		Main.	Tail.
		yds.	yds.
Ropes, or Chains	Length	2232	4491
		in.	in.
	Circumference ..	3½	3
		cwts. qrs. lbs.	cwts. qrs. lbs.
	Weight ..	233 0 23	336 0 2
		months.	months.
	General duration	24	24
Sheaves ..	Number ..	146 37 50	142 31 60
		lbs lbs. lbs.	lbs lbs. lbs.
	Weight per sheave ..	39 26 40	39 26 40
		inches.	inches.
	Diameter ..	6 6 9	6 6 9
		ft.	ft.
	Distance apart ..	24	24
		in.	in.
	Extra sheaves at curves, &c. ..	29 at 10	24 at 6 17 " 10
			lbs.
	Return sheave, weight		952
			ft. in.
	" " diameter ..		7 0

Description of Plane.—The plane is laid with broad-topped rails, in 15-ft. lengths, weighing 20 lbs. a yard. The way is laid on chairs 3 ft. apart, and the gauge of the way is 2 ft. 4 in. There are three slight curves on the plane, all turning in the same direction; the radius of No. 1 curve is 10 chains; No. 2, 10 chains; and No. 3, 12 chains. Nos. 1 and 2 curves are close together. The ropes are carried round the curves by bell-sheaves 10 in. in diameter. The usual distance of the rollers apart is 24 ft., but this is not always observed; there are three descriptions of rollers used, the 6-in. rollers being most common both for the main and tail rope.

The ropes run off and on to the drums on the upper side, and are carried near the roof to the station. The tail wheel inbye is also placed near the roof, and the ropes are raised to it by sheaves.

This plane is worked in very much the same way as the majority of tail-rope planes in this district, but instead of having the usual kep for the full tubs to run down upon to the shaft, the way is laid level, and the coals are led from the station to the shaft by horses. On the end of both main and tail ropes there are fixed about 15 yds. of chain, with two or three large links inserted at various distances apart, and one of these links is attached by an iron pin to the loop of the centre bar of each end tub of the set, according to the position of the set at the station. In taking the empty set of tubs inbye, the tail rope is first connected to the set, and then the main rope, and the set is drawn inbye by the tail-rope drum, the main-rope drum being out of gear, with just a slight weight hung upon the brake-lever, to prevent the drum from over-running the rope. When the set reaches the inbye station it is allowed to stop before knocking off the ropes. The full set is brought out in a similar way by the main-rope drum, the tail drum running loose on the shaft, with a light weight on the brake-lever.

Harraton Colliery, near Durham.—In the application of the tail-rope system at this colliery two branches are worked, and the average gradient is in favour of the full tubs.

The engine-plane is 1795 yds. long to the north-way terminus, and 1729 yds. to the west-way terminus. The average gradient from the north-way flat to the shaft is a dip outbye of 1 in 83.

At present about 650 tons a day are led along this plane, nearly equal quantities being led from each of the branches.

The hauling engine is vertical, and has two 20-in. cylinders. The drums are 5 ft. 2 in. diameter, and the ratio of the pinion to the spur-wheels is as 3 to 4, thus causing the drums to make one-third more revolutions than the engine.

The three boilers by which steam is supplied are on the surface, and connected with the other boilers employed on the surface. Jucke's furnaces are used for firing. The engine works both day and night, but at present is doing very little work at night. The engine-plane has been at work only five years, and the engine, rails, tubs, and so on, are in very good condition.

The lead from the engine to the terminus of the plane near the shaft is not direct, the ropes being taken by large sheaves round a right angle 27 yds. from the engine.

DIMENSIONS OF ENGINE.

Number of cylinders	2	
	ft.	in.
Diameter of cylinders	2	2
Length of stroke	3	0
Diameter of piston-rod	0	3½

	ft.	in.
Length of connecting rod	6	0
	in.	in.
Dimensions of steam-ports	17 × 1¾	
" " exhaust "	17 × 2	

DIMENSIONS OF ENGINE—*continued.*

	Steam.	Exhaust.
	ft.	ft.
Length of breech-pipe	27	20
„ main pipe	570	251
	in.	in.
Diameter of breech-pipe	5	6
„ main pipe	9	7

	ft.	in.
Diameter of driving pinion	4	2
„ followers	3	2
„ fly-wheel	8	2

Description of Engine-plane.—The plane is laid with heavy-topped chair rails, weighing 22 lbs. a yard. There are two curves on this plane, both 26 yds. radius; No. 1 curve being 66 yds. long, and No. 2, 80 yds. The main rope is taken round the curves by sheaves, 4 ft. in diameter, with several 2-ft. sheaves placed close enough together to form an almost regular curve for the rope. The tail rope is taken round a 6-ft. wheel at No. 1 curve, and a wheel of 8 ft. diameter at No. 2 curve.

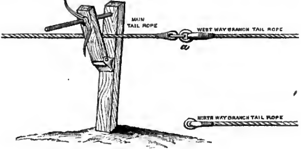
The return wheels are 8 ft. diameter, and are placed diagonally. The main rollers are 8 in. diameter, and the tail-rope rollers 13½ in. diameter. The large pulleys used on this plane have wrought-iron rods for spokes.

At No. 2 curve the inner rail is laid about 3 in. higher than the other. Though the set passes round this curve at the rate of ten miles an hour, no accident has ever occurred.

Description of the Method of Working the Plane.—There are 63 tubs in a set. In going inbye the set is attached to the rope by two knock-off links, and is taken to the junction A. As the set is taken nearly alternately into each of the branches, the arrangement of ropes is altered at this junction, as the ropes of the way last visited are then on the set. Suppose the set has been last in the west way, in going inbye again, when it has arrived at this junction, the tail rope at the inbye end of the set is removed, and replaced by the north-way rope; the shackle connecting the main tail rope with the west-way branch rope being held by a wooden clamp, fixed at the junction, while the end of the north-way rope is being attached to it. This shackle-joint is stopped always at the same place; and as the branch-rope end is brought to this point whilst the set is coming inbye, they are connected immediately. As this connection is made by the man attending the junction, while the connection at the end of the set is being made by the run-rider, the time taken up by the change is very short, generally not more than two minutes.

The annexed sketch, Fig. 3909, shows the position of the ropes just when the tail rope has brought the shackle-joint near to the clamp, which is then screwed up. As before described, the west-way rope is then taken off, and the north-way rope connected. When the end of the north-way rope is not just opposite to this point, it is drawn up by a winch, fixed here for the purpose.

3909.



In coming *outbye*, the set (from either way) comes out to the shaft without stopping. At the fore end of the set is fixed the self-acting knock-off link, Fig. 3910. When the set arrives at the top of the kip, and most of the tubs are over the brow, a piece of iron, fixed to the roof, comes in contact with the arm A of the knock-off apparatus, and releases the main rope, which falls off to one side. The engine is then stopped, and the set is let down by the tail rope, which is still attached, till the first tub (if there are no full tubs standing) reaches the shaft. Whilst going down, spraggs are put into the tub wheels, by means of which the tubs are afterwards let down to the shaft as required.

3910.

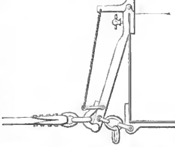


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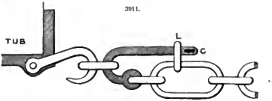
Fig. 3911 represents the knock-off link used at the other end of the set. When the rope has to be disconnected, the cotter at C is removed, and the link L is pushed off by the foot.

3911.



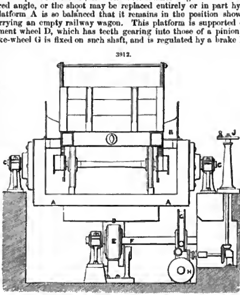
Rigg's Apparatus for Carrying and Tipping Coal, Figs. 3912 to 3917.—This invention of A. Rigg, jun., has for its object the formation of an improved apparatus for carrying and tipping coal and other minerals. The apparatus consists of a platform sustained on axles or rollers which carries the wagon or other receptacle containing substances to be upset, the centre of motion being so adjusted that when full the weight of minerals overturns the whole, and when empty returns to the original position, unless restrained. Towards that portion of the wagon which descends lowest in overturning is fixed a plate or riddle, movable with the machine and attached to it at any angle, either curved or straight.

For the larger sizes of machines the inventor prefers steam-brakes, which possess a cylinder closed at both ends; a large passage communicates steam to the upper or impelling side, and a smaller opening supplies the lower or retreating side, and to this side is connected a large escape tap or valve to be regulated at will, or the inlet to the lower side may be made to reduce as the exhaust or escape valve opens. Any extent of pressure may be obtained by enlarging the escape, while the inlet to the upper side remains unaltered, and the brake may be thrown out of action by closing the exhaust-valve. This form of brake is also applicable to steam-engines or other machinery.

Figs. 3912, 3913, represent end and side elevations of one modification of this tipping machine for loading wagons and ships; it is easily perceived that the principle admits of variation to suit any size or description of wagon, whether with end doors opening or not.

By reference to the Figures above mentioned it will be seen that the apparatus consists mainly of a platform A, carrying a shoot B at one end, which shoot may be horizontal, as shown in Figs. 3912 to 3917, for railway trucks open at the ends, or vertical for smaller wagons with closed ends, or it may be at any desired angle, or the shoot may be replaced entirely or in part by a screen or curved plate. The platform A is so balanced that it remains in the position shown, and returns to it even when carrying an empty railway wagon. This platform is supported on two axles C, C, and upon a segment wheel D, which has teeth gearing into those of a pinion E on the brake-shaft F. The brake-wheel G is fixed on such shaft, and is regulated by a brake H, where steam or other elastic medium is available. A hand-wheel J or other regulator placed in some convenient situation, determines when the brake shall be brought into operation or thrown out of use. On a loaded wagon being placed on the platform, a powerful tendency to overturn is at once manifested, but such tendency is checked and controlled by the brake, for it will be observed that the centre of gravity of the coal or other mineral is considerably in advance of the centre of motion of the tipping machinery. On the end door of the wagon being opened, and the tipping movement allowed to continue, the minerals or materials slide easily down the shoot into the boat or other depository. It is necessary that a greater inclination should be given to the part of the shoot next the wagon, in order to remove all the coal, than is proper for the outer end of the shoot, for which reason the curved portion at the end is applied, which comes into action and checks what might otherwise prove a damaging velocity. The dotted lines explain the movements just described.

3912.

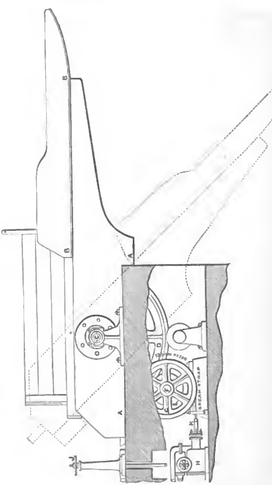


After the delivery of the coals or minerals, the apparatus returns into its horizontal position, such return being regulated in its speed by the brake.

Figs. 3914, 3915, represent on a larger scale the brake 11 above mentioned. From the side elevation and section, Figs. 3914, 3915, it will be seen that the apparatus consists of a cylinder H with piston K, similar to that of a steam-engine, and it is preferred to make the piston-rod of larger diameter than is usual for a steam-engine, partly for security. A constant communication exists between the boiler and the upper side of the piston, and also between the boiler and the valve-chest. In this valve-chest one passage leads to the lower side of the piston, and the other to the exhaust.

The valve is shown in Figs. 3915 to 3917, and is arranged to cover both ports. Figs. 3916, 3917, show side and end elevations of the valve, which has a passage (1) completely through it corresponding to steam-port at the lower end of the cylinder, and a recess (2) which is arranged to cover the exhaust and steam ports when necessary; while the opening (1) in the valve corresponds to the port leading to the lower side of cylinder, an equal pressure is maintained on both sides of the piston, except what is due to the diameter of piston-rod, which difference always keeps the brake-band slack when out of action. When the valve is turned so that the recess (2) in the valve covers both the steam and exhaust ports, an escape of steam will take place, which, by reducing the pressure on the lower side of the piston, whilst the pressure at the upper surface of the piston remains in full force, causes the brake to come into action with a force depending on the rapidity of the escape of steam allowed. The brake will be put out of action by turning the valve, so as to allow a free flow of steam again into the lower end of the cylinder. By making the partition in the valve somewhat narrower than the opening of the port, steam can be partially admitted while some escapes, thus giving a greater range of pressures, and maintaining as long as required the necessary force.

3913

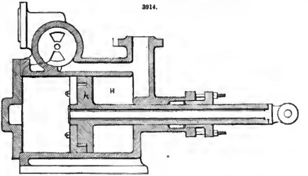


Murton Colliery, County of Durham.—There are no branches worked by the tail rope at this colliery; but there is a station (Hallfield station) by the side of the main way, from which part of the coals are led.

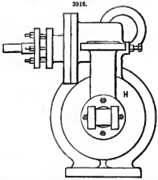
The length of plane the coals are led over from the south-east or far-off landing is 2770 yds., and 1978 yds. from the Hallfield station, the distance from the engine to the tail wheel being 2816 yds.

The hauling engine is a double 18-in. cylinder horizontal engine, with 2-ft. stroke. The main and tail drums are 5 ft. in diameter, and on the second motion the revolutions of the pinion-wheel to the spur driving the main drum being as 2·387 to 1, and as 1·581 to 1 to the spur-wheel driving the tail drum. The drums are put in and out of gear by shifting carriages.

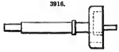
3914.



3915.



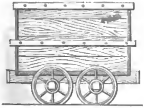
3916.



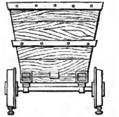
3917.

Dimensions of Tubs, Figs. 3918, 3919.—Length inside, 3 ft. 9 in.; breadth at top, 3 ft.; breadth at bottom, 2 ft. 1 in.; depth, 2 ft. 4½ in.; height above rails, 3 ft. 5 in.; distance coupled, 1 ft. 6 in.; diameter of wheels, 1 ft. 2 in. Total number in pit, 450. Number required to work engine-plane, 288.

3918.



3919.



Description of Engine-plane.—The plane is laid with chair rails, in 12-ft. lengths, weighing 24 lbs. a yard; the gauge of the way is 2 ft. 8 in. The tub used has wheels 14 in. in diameter, and carries about 10 cwt. of coals.

There are two curves on the plane. No. 1 curve has a radius of 154 yds., and No. 2 a radius of 42 yds. The average gradient of the plane is 1 in 83 rise outbye, and the heaviest gradient is 1 in 25; part of the plane is level, but no part of it dips towards the shaft. The rollers and sheaves used for carrying the rope are for the most part 6 in. in diameter. The main rope is taken round No. 2 curve by drum-sheaves, 2 ft. in diameter, and the tail rope by ordinary 2-ft. sheaves.

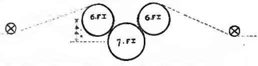
At the Hallfield landing there is a pair of switches leading on to a double line of rails, for full and empty tubs.

The lead for the ropes from the drums to the engine-plane is direct. The main rope is 2¾ in. in circumference when new, and the tail rope 2½ in.

Near to the Hallfield landing there is a three-cranked single-action force-pump, worked by the tail rope by means of three friction-wheels placed as shown in Fig. 3920.

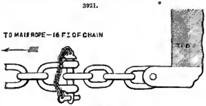
A similar pump is worked by the tail wheel. It is difficult to arrive at the share the pumps have in the wear and tear of the ropes, but it is estimated in the account of cost of maintenance at one-third of the whole cost; that is, were the pumps and the wheels necessary to drive them done away with, the tail rope, instead of lasting six months, as at present, might be worked for nine months.

3920.



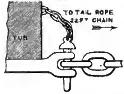
Description of Method of Working the Plane.—There are forty-eight tubs in a set of full or empty tubs. No run-rider is employed. The main rope is attached to the set by fastening the shackle, which is on the end of the chain, to the coupling chain of the end tub, with a pin, which is secured by a spring cotter, Fig. 3921; and the tail rope is attached by placing the end link of the chain in the centre bar, securing it by the pin, which is a fixture on the end of the tub, Fig. 3922.

3921.



Fastening at the Main-rope end.

3922.



Fastening at the Tail-rope end.

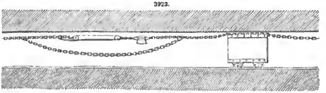
In going inbye, when the ropes are attached to the set, the station boy raps to the brakesman, and the set is started. The set is always stopped at the Hallfield landing, till a rap is given from there telling the brakesman into which way he has to go; if for the Hallfield way, the switches are opened, and the set passes on to the empty siding. When the ropes are disconnected, the set runs a short distance along the siding, in order to allow the ropes to be attached to the full set. When the set goes into the south-east way, no rap is given on the set reaching the flat, as the brakesman knows from the position of the rope upon the drum when to stop the engine. The full set is generally standing as nearly as possible opposite to the point to which the empty set runs. Should the set, however, here, or at either of the other stations, not be conveniently situated for the ropes, a lengthening chain (several of which are kept in readiness) is put on, and it is thus very seldom necessary to move the ropes.

In coming outbye, when the set arrives at the bankhead, the station boy raps to the engineman (by a rapper distinct from the main rapper), and the full set is stopped opposite the empty set, part or all of which is generally standing ready to go inbye. When the set stops, the pin fastening the main rope to the set is usually very tight, and has to be drawn out by a lever kept for the purpose. This method of attaching is not so convenient as the slip-link fastening, by which the rope can be easily disconnected by the foot.

From the bankhead the coals are taken about half-way to the shaft by a tail rope; the tail rope is then knocked off, and the set runs to the shaft, dragging the main rope after it. The main rope afterwards draws the empty set up. The cog-wheel for driving the small drums required for this work is under the pinion-wheel of the engine, and can be put in and out of gear whilst the engine is working the main engine-plane, by reducing the speed of the engine for a short time.

Experiments with Dynamometer.—The dynamometer was tried only upon the main ginney road, Nos. 1 and 2 ginney roads being too low to admit of its being used with safety. It was first brought in on the empty-tub way, and then taken out on the full way. Three other experiments were also made to find the tractive power required to work the main road, and the two branches working separately; these were made in the first 248 yds. from the station, rising 1 in 17, and the readings were noted at three different places on the bank. The dynamometer was attached to the chain, as shown in Fig 3923, by coupling chains on one side, and blocks on the other; the blocks were then drawn up, and the main chain made slack.

3923.



ABSTRACT OF EXPERIMENTS WITH INDICATOR.

Series.	Description of Work.	Steam Lbs.				Speed of Piston.		Actual Horse-power.
		Gauge on Boiler.	Indicator.			Strokes a min.	Feet a min.	
			Steam.	Back.	Effective.			
A	Engine going full work, both winding and ginney chains going in shaft, and Nos. 1 and 2 ginneys underground ..	32¼	24·1	7·8	16·3	60	240	29·11
B	No. 1 ginney going alone	33½	22·6	5·6	17·0	60	240	30·36
C	No. 2 ginney going alone	34	23·11	6·05	17·06	60	240	30·47
D	Nos. 1 and 2 ginneys not working, and both chains going in shaft; winding full tubs	32	22·8	6·0	16·8	60	240	30·00
E	Nos. 1 and 2 ginneys not working, and both chains going in shaft; winding empty tubs	32	3·8	1·6	2·2	60	240	3·93
F	Winding chain going alone in shaft, winding empty tubs; all ginney chains being out of gear	32½	8·5	1·6	1·9	60	240	3·39

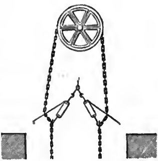
Power required to work the engine, together with the winding chain working empty tubs in the shaft, all the endless chain being out of gear, and the chain in the shaft being disconnected from driving wheel by blocks, as shown in Fig. 3924 (F); at 60 strokes a minute, 3·39 horse-power.

Power required to work the engine, together with the winding chain, and the hauling endless chain in the shaft, and underground to the pulley, all other underground chains being out of gear, see E tabulated form; at 60 strokes a minute, 3·93 horse-power.

∴ Power required to convey the endless chain down a shaft 75 ft. deep, and underground for a distance of 27 yds.:—

	Both chains.		Winding chains alone.		Horse-power.
At 60 strokes a minute	3·93	−	3·39	=	0·54

3924.



CALCULATION OF FRICTION OF CHAIN IN SHAFT.

	cwt.
Moving weight.—Pulleys, 2 at 4 cwt.	8
„ 2 at 1 cwt.	2
„ for tightening chain at bottom	1
Suspended weight (W on section)	8
	— 19
Chain.—The two sides of the chain in the shaft counterbalance each other, so that only the horizontal chain is to be considered; 27 yds. × 2 = 54 × 16 lbs. a yard	7·7
	26·7

Speed of chain in shaft, 156 ft. a minute. Then $\frac{\overset{\text{h. p.}}{\cdot 54} \times 33000}{112 \times 156 \text{ ft. a minute}} = 1\cdot 02$ cwt.

Then total friction $= \frac{1\cdot 02}{26\cdot 7} = \frac{1}{25}$ of total weight of horizontal chain, pulleys, &c.

Power required to work engine and wind coals, and to drive all the endless-chain roads underground, the average gradient of which is a fall outbye of 1 in 20 (A); at 60 strokes a minute, 29·11 horse-power.

Power required to work engine, wind coals, and to drive No. 1 ginney road only (B); at 60 strokes a minute, 30·30 horse-power.

Power required to work engine, wind coals, and to drive No. 2 ginney road only (C); at 60 strokes a minute, 30·47 horse-power.

It would appear from the three experiments above, that it requires less power to work both ginney roads together, than when going separately. The power required for winding coals by this system is shown by this experiment to be

$\text{Engine, \&c.}$
30·00 − 3·39 = 26·61 horse-power, to wind 417 tons 75 fas., a day of 8½ hours.

Power required to work engine and wind coals—the hauling chain in the shaft being also in motion, but all the underground ginney roads being out of gear (D); at 60 strokes a minute, 30·00 horse-power.

From this it will be seen that the working of the underground ginney roads assists the winding of the coals to the extent of 30·00 − 29·11 = ·89 horse-power.

Endless-rope System.—The method of conveying coals by this system of applying the endless rope has hitherto been very rarely adopted. It is chiefly in operation in the Midland Counties. The following planes have been reported on, but experiments have been made at the first only:—

I.—Shireoaks Colliery, Nottinghamshire—Underground plane in a straight line, and rising towards the shaft.

II.—California Pit, Wigan—Three underground planes, branching from the pit, and worked by one engine; a short curve on one of the planes.

Varieties of the No. 1 endless-rope system are in operation at the following collieries:—

III.—Newsham Colliery, Northumberland—Straight undulating plane, with no branches.

IV.—Eston Mines, Yorkshire—A short rope working three branches from a main line.

V. Cinderhill Colliery, Nottinghamshire—Level plane, with no branches; endless rope worked at slow speed.

This system is a modification of the tail-rope system. The following are a few of its chief characteristics:—

1. The rope, as the name implies, is endless.

2. To give motion to the rope a single wheel is used, and friction for driving the rope is supplied either by clip-pulleys, as at Shireoaks, Newsham, and Eston, or by taking the rope over several wheels, as at the Cinderhill and California Pits.

3. As only one driving wheel is used, the rope has to be kept constantly tight; this is effected by passing it round a pulley fixed upon a tram, to which a hanging weight is attached.

4. Either one or two lines of rails are used; when a single line is adopted, as at Newsham, the rope works backwards and forwards, only one part of it being on the wagon-way, and the other running by the side of the way; when two lines are used, as at Shireoaks, Cinderhill, and the California Pit, the rope moves always in one direction, and the full tubs come out on one line, the empties going in on the other.

5. The set of tubs is connected to the rope either by means of a clamp, or by sockets in the rope, to which the set is attached by a short chain. The former method is in use at Shireoaks, Cinderhill, and the California Pit, whilst the latter is adopted at Newsham and Eston Mines.

6. The working of curves and branches has hitherto been scarcely attempted by this system. At California Pit there is a slight curve on one of the ways, which works well.

The various methods of applying this system are described in the following Reports of the planes visited.

Shireoaks Colliery, Nottinghamshire.—The No. 1 endless-rope system has been in operation at Shireoaks Colliery for about four years. The engine by which the rope is worked is a double horizontal engine, with two 12½-in. cylinders. The boiler is single tubular, with Galloway's cross-tubes, and is placed underground at a very short distance from the engine.

DIMENSIONS OF ENGINE, BOILER, AND ROPES.

Engine erected 1856.

Number of cylinders	2	
	ft.	in.
Diameter of cylinders	0	12½
Length of stroke	2	0
Diameter of piston-rod	0	$1\frac{9}{16}$
Length of connecting rod	5	10
	Steam.	Exhaust.
	ft.	ft.
Length of breech-pipe	0	1½
" main pipe	62	64
	in.	in.
Diameter of breech-pipe	0	3¾
" main pipe	4	4½
	ft.	in.
Diameter of driving pinion (friction gear)	2	8
" followers	4	0
" fly-wheel	None	
" clip-wheel	4	0
Distance between centres of cylinders	2	5
Boiler .. Number	1	

Description—Single tubular, with 3 Galloway's tubes.

Area of heating surface, 494 sq. ft.

		ft.
	" fire-grate	19
		ft. in.
Boiler ..	Length over all	25 0
	Diameter	6 0
		ft. ft. ft.
	Hot-water tank (through which exhaust passes)	9 × 6 × 4
		yds.
Rope ..	Length	1590
		in.
	Circumference	2½
		cwts. qrs. lbs.
	Weight	25 2 21
		months.
	General duration	18
Sheaves (*wood*)	Number (53 on each way)	106
		lbs.
	Weight a sheave	14
		in. in.
	Diameter	5 × 16
		ft.
	Distance apart	45
		lbs.
Rails ..	Weight a yard	18
		ft.
	Length of each	12
	No. of lines	4
		ft.
	Gauge of way	2
	General condition	Good

DIMENSIONS OF TUBS.

	ft.	in.
Length inside	3	8
Breadth	3	0
Depth	1	5
Height above rails	2	4½
Distance coupled	1	4¾
Diameter of wheels	0	7⅛

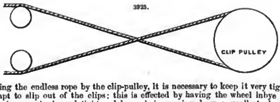
Total number in pit	450
Number required to work endless-rope plane	256

Work done, 320 tons a day of 11 hours (1 hour allowed for meals).

Description of Engine-plane.—The engine-plane is laid with a double way; the empty sets going in on one side, and the full sets coming out on the other. It was originally intended to have sets coming out and going in at the same time, but the limited quantity of coals now being drawn renders this unnecessary. The plane worked by the endless rope is 750 yds. long, with an average rise towards the shaft of 1 in 48; the heaviest gradient being 1 in 29. The same engine also draws coals along a single-rope plane, 737 yds. long, the average rise of which, towards the shaft, is 1 in 15. One of Fowler's clip-pulleys, 4 ft. in diameter, is used, to give motion to the endless rope. The wheel is in a horizontal position, and is connected by mitre-gearing to the friction-gearing by which it is worked. The pinion friction-wheel is 2 ft. 8 in. in diameter, and drives two spur-wheels of 4 ft. diameter, one for the clip-pulley and the other for the single-rope drum. The friction-gearing is found to answer exceedingly well, and is very convenient for putting out of gear, a movement of ¾ in. being sufficient to disconnect the wheels; this is effected by the shafts of the spur-wheels being placed in eccentrics.

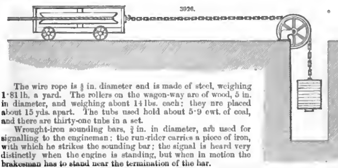
As it was found desirable, in the adoption of the clip-wheel, to cause the rope to pass round as large a circumference of the wheel as possible, in order to get as much of the grasping effect of the clips as practicable, the ropes at a short distance from the clip-wheel are crossed, as shown in Fig. 3925.

3925.



In working the endless rope by the clip-pulley, it is necessary to keep it very tight, as otherwise it is apt to slip out of the clips; this is effected by having the wheel inbye placed on a carriage moving on wheels, and tightened by a chain, passing down a small staple, as shown in Fig. 3926, to which a weight of about 15 cwt. is suspended. The weight descends as the rope stretches, and thus constantly keeps the rope at the same tension.

3926.



The wire rope is ⅝ in. diameter and is made of steel, weighing 1·81 lb. a yard. The rollers on the wagon-way are of wood, 5 in. in diameter, and weighing about 14 lbs. each; they are placed about 15 yds. apart. The tubs used hold about 5·9 cwt. of coal, and there are thirty-one tubs in a set.

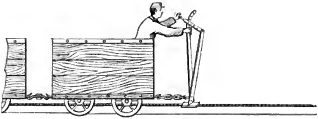
Wrought-iron sounding bars, ¾ in. in diameter, are used for signalling to the engineman; the run-rider carries a piece of iron, with which he strikes the sounding bar; the signal is heard very distinctly when the engine is standing, but when in motion the brakesman has to stand near the termination of the bar.

Description of the Method of Working the Engine-plane by the No. 1 Endless-rope System.—The rope in passing from the clip-pulley on the outhye end, and to the tail wheel at the inbye end, goes under the rolley-way for about 80 yds.; the tubs can thus pass over the rope in coming from the shaft, Fig. 3927.

In taking the set inbye, the tubs are coupled together at the bankhead, and the run-rider, who rides in the first tub at the front end of the set, first hooks the chain affixed to the clamp on to the iron loop at the end of the centre bar of the tub, and then fixes the clamp upon the rope, which is always upon the middle of the way; this clamp is closed by a handle-lever, passing over the curved end, and by the insertion of an iron pin is kept firmly fixed without the pressure of the hand. The clamp has such a strong hold upon the rope, that in a case of the set being stopped by some obstruction, the rope has been found to break rather than slip through the clamp.

The clamp having been fixed to the rope, the run-rider strikes the sounding bar, and the rope moves forward, the man pressing upon the handles of the clamp to keep it perpendicular, and the tubs being pulled forward by the chain on the clamp. The set at the start is about 45 yds. from the engine, and is on a gradient of 1 in 520 fall; the next or middle gradient is 1 in 47. As the set is found to overrun the clamps in going inbye at this latter gradient, six spraggs are placed in the wheels of the tubs at the end of the set, to prevent the tubs getting together and becoming uncoupled. At a distance of 364 yds. from the engine, and about the middle of the 1 in 47 gradient, the clamp is taken off the rope whilst in motion, and the set runs forward by itself. When the clamp is disconnected, the run-rider raps to the engine—though the running away of the rope when disconnected is sufficient to let the brakesman know—and the rope is stopped, the engine then being free to work the single-rope way.

3927.



There are two stations from which coal is being drawn at present; the first being 640, and the second about 795 yds. from the engine. When the gang or set has to go to No. 15, or the first station, the points are placed for this, and the set, then disconnected from the rope, runs round the curve into the station; the rope at this curve passes under the rolley-way, so that with this arrangement the clamps could not pass this point. When the set is intended for the far-off station, or No. 13, it runs by itself from the knock-off point, the spraggs being taken out, when necessary, by a boy, who rides with the set for the purpose.

In coming outbye, the clamp is also placed at the front end of the full set, which is pulled out to within 140 yds. of the engine, when the clamp is removed, and the tubs run forward to a point from which they are taken to the shaft by horses. The expressions *outbye* and *inbye*, which occur frequently in this Report, are terms used in the North of England; the former to denote the end of the engine-plane nearest to the shaft, and the latter the end nearest to the workings of the mine.

When bringing the full tubs out, the strain of the full set upon the clamp chain raises the rope a little and prevents the clamp from striking the rollers; but in going inbye, where there is much less strain, the clamp, in passing over the rollers, touches them slightly.

The engine cannot pull coals from the endless-rope way and the single-rope way together, and if this were possible, it would be hardly worth while, since it never goes for more than 3½ minutes at a time in working the endless rope.

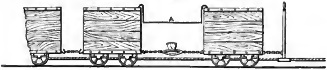
EXPERIMENTS WITH DYNAMOMETER.

Series.	Work done	No.	Time.	Reading of Dynamometer.	Distance travelled in yards.	Speed. Miles an hour.
			h. m. s.	cwt.		
A	*Full tubs coming out.*		12 0 0	..	..	..
	.. ..	1	12 0 30	14	..	..
	.. ..	2	12 2 15	10	..	..
	.. ..	3	12 3 1	5	..	..
		..	12 3 40	..	655	6·10
B	*Empty tubs going in.*					
	.. ..	3	1 0 0	..	..	..
	.. ..	2	1 0 43	1	..	..
	Knocked off	..	1 2 05	1	..	..
		..	..	..	319	3·6

These experiments were made with a set of thirty-one tubs, the dynamometer being placed between the first and second tubs.

A piece of iron, A, placed between the two tubs, Fig. 3928, kept them at a regular distance apart, and prevented the possibility of the chain, by which the dynamometer was suspended, becoming slack.

3928.



California Pit, near Wigan.—At this pit the endless rope is worked on the same plan as that in operation at Shireoaks Colliery. As experiments were made at Shireoaks to shew the power required for a certain gradient with this endless rope, it was thought that a few notes of the mode of applying the system at the California Pit would be sufficient to shew anything different in the application of it from what has been already described.

The engine by which the planes are worked is underground. It has two 14-in. cylinders and a 2-ft. stroke.

There are three distinct planes worked by this engine, all falling from the shaft. The following are some general particulars of each of the planes;—

Name.	Length.	Average gradient. (Approximate.)	No. of tubs a set.	Time required to bring set out.	Tons led a day.
North Level	620	⅜ in. a yard	20	3 minutes	130
Down Brow	1370	2½ "	12	4 "	120
Duke's Slant	740	3 "	20	7 "	180

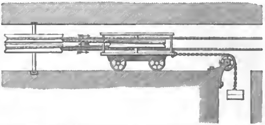
The tubs used hold 6 cwt. Each of the three ways is worked by two driving wheels, acting as one wheel with a double trod; these wheels are all close to the engine, and are horizontal. Motion is transmitted to the driving wheels by mitre-gearing. By an arrangement each of the driving wheels can be put in and out of gear when necessary; the three handles required for this are close together in the engine-house, and mitre-gearing is also used for working them.

The rope used for all the ways is of steel, ⅝ in. diameter. The planes have been at work about 3½ years, and the duration of the ropes is found to be about three years.

The rollers on the plane are 6½ in. in diameter, and are placed about 20 yds. apart.

Description of Method of Working the Plane.—As at Shireoaks, the ropes have to be tightened, in order to prevent them from slipping off the pulleys at the two ends of the planes. The tightening is effected by having, a few yards from the double driving wheel, another pulley fixed on a movable tram, round which the rope is passed. A chain is attached to this tram, to which a weight is connected; this weight is hung in a staple, as shown in Fig. 3929, and keeps the rope constantly tight.

3929.



The weights required to tighten the rope for each of the ways are—

	cwt.
North Level	30
Down Brow	30
Duke's Slant	40

All the arrangement of driving wheels and tightening pulleys is under the way. The rope comes on to the wagon-way about 8 yds. from the driving wheel.

The number of tubs in a set is twelve on the Down Brow and twenty on the other planes. The highest average speed is on the Down Brow way, where the tubs run at a speed of 11·7 miles an hour.

A double way is laid the whole length of each plane. On the Duke's Slant and Down Brow ways an empty set is taken in and a full set brought out simultaneously, and as the gradient of both of these planes is considerable, the load upon the engine is lightened by this arrangement. The two planes referred to are sometimes worked together in this way, but they cannot be worked at the same time when the engine is hauling the full coals out, without the assistance of the ingoing empty tubs. This double journey on both of the planes requires the services of four gang-riders. There is only one regular gang-rider; and when others are required, they are taken from the stations at the inbye ends of the planes.

The clamp used at this pit for connecting the sets of tubs to the rope is different from that used at Shireoaks, in being secured by a ring passing over the ends of the arms, instead of a lever.

On the Duke's Slant and Down Brow ways the rope is connected to the set at the fore end in coming out, and at the back end in going in; and on the North Level, the gradient of which is much lighter, the set is connected at the fore end in going both directions.

There is a short curve of 4 chains radius on the North Level way, round which the rope and clamp pass easily, though not at a higher speed than seven miles an hour.

Newsham Colliery, Northumberland.—At this colliery the No. 1 endless-rope system is worked, as at Shireoaks, by the clip-pulley.

The chief peculiarities in the working of this engine-plane are as follow:—

1. Only one way is used, the empty and full tubs running on the same road, and half of the rope being carried on sheaves by the side of the way.

2. Instead of the clamp, used at Shireoaks, the set of tubs is connected to the rope by two short chains, one end of the chain being secured to the tub at each end of the set, and the other attached to a socket in the rope.

3. The plane is undulating, and thus presents one of the most awkward difficulties to contend with in the working of this system.

The endless rope is worked by a clip-pulley, driven by one of Fowler's engines. It is placed underground, and is worked generally at a speed of eighty-five strokes a minute, with a pressure of 80 lbs. of steam.

Dimensions of Engine, Boiler, and Ropes.

Engine erected 1867.

Number of cylinders		2
Diameter of cylinders		12 in.
Clip-pulley, diameter		7 ft. 6 in.
Boiler ..	Number	1
	Size	15 ft. 5 in. × 3 ft. 6 in.
	Coal consumed a day (splint)	9 cwt.
Rope ..	Length	1672 yds.
	Circumference	2½ in.
	General duration (estimated)	2½ years.

		Main.	Tail.
Sheaves ..	Diameter	4½ in.	8 in.
	Weight	28 lbs.	31 lbs.
	Distance apart	16 yds.	16 yds.
	Sheaves at curves (diameter)	3 ft.	
	" (weight)	224 lbs.	
Rails ..	Weight a yard		28 lbs.
	Gauge of way		2 ft. 8 in.
Tubs ..	Average weight (empty) ..		672 lbs.
	" (coal contained)		1120

Dimensions of Tubs.

	Wood. ft.	Wood. in.	Iron. ft.	Iron. in.
Length inside	3	9	3	10
Breadth	2	9	3	1
Depth	2	0	2	2½
Height above rails	3	6	3	6
Distance coupled	1	9	1	10

	Wood.	Iron.
Diameter of wheels	1 ft. 4 in.	1 ft. 4 in.
Total number in pit	83	100
Number required to work endless-rope plane	96	

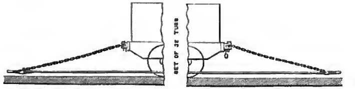
Work done, 400 tons a day of 12 hours.

Description of Engine-plane.—The engine-plane is laid with flat-bottomed rails, weighing 28 lbs. a yard. There are two very slight curves on the plane, round which the main rope works easily in the centre of the way. The rope by the side of the way is taken round these curves by 3-ft. sheaves. The length of the plane is 836 yds. The road first rises from the shaft at a gradient of 1 in 40 for a distance of 318 yds., and then falls for a distance of 379 yds., at an average gradient of 1 in 47, the average gradient of the plane being a fall towards the shaft of 1 in 805.

The rope used is steel. By means of a bearing-down pulley, the rope is made to move in nearly the whole circumference of the clip-pulley. The rope has been in use for eighteen months, and is expected to last another year. It is kept tight, as at Shireoaks, by having a hanging weight attached to the sheave at the inbye end of the engine-plane. The weight used here is about 25 cwt.

Description of the Method of Working the Engine-plane.—The full and empty tubs are run in sets of thirty-two tubs. The sets are attached to the rope by chains, 7 ft. long, as shown in Fig. 3930.

3930.



There are two sockets in the rope, placed at a distance apart convenient for the attachment of a set of thirty-two tubs, to which these chains are connected. The chains are put on at both ends of the set, the undulations of the plane rendering this necessary. The connection with the set is made simply by hooking on, and with the rope by a screw-shackle.

At each end of the plane the rope passes under the way, and in going in and out, when the set comes to this point, it is disconnected from the ropes, and the gradient of the way is so arranged that it runs by itself into the siding.

In going from the shaft, the set of tubs having fallen to the point at which the rope passes from under the way, the chain is attached to the fore end of the set; the engine then moves the set forward over a distance equal to the full length of the set, and the back chain is hung on. The moving of the set forward causes the coupling chains between the tubs to become tight, and the danger of the set overrunning the chain at the fore end of the set, when the gradient falling from the shaft is reached, is thus avoided.

There are no swivels on the chains connecting the set to the rope, the tightness of the rope rendering them unnecessary.

The sets are taken in and onthye, at an average speed of ten miles an hour. In disconnecting the set from the rope at the inbye end, the chain at each end of the set is taken off the tubs, but is not disconnected from the socket on the rope; this is done before the set reaches the siding, whilst it is moving slowly; when detached, it runs forward into the siding. At the shaft the leading chain is disconnected from the rope first, and then from the tub; this is done to allow the shackle to pass over the clip-wheel, which is placed rather close to the terminus of the engine-plane. The chain at the other end of the set is taken off the tubs only.

Endless-rope System.—This system of conveying coals is only in operation in the Wigan district, where it has only been in use for a few years. Of the four systems reported on it is probably the least known. Reports are given on the following planes. Experiments were made and costs extracted at the Bridge and Meadow Pits only:—

I.—Bridge Pit—Several planes at work, with an average gradient rising towards the shaft. One self-acting curve working.

II.—Meadow Pit—Single plane rising towards the shaft.

III.—No. 5 Moor Pit—Single plane, rising at a heavy gradient towards the shaft.

IV.—Mesnes Colliery—Undulating plane, worked by an engine on the surface.

V.—Scot Lane Pit—Single short plane, with peculiar method of connecting the tubs to the rope.

The principle on which No. 2 endless-rope system is worked is very similar to that of the endless-chain system.

The following are the chief peculiarities in the application of this system:—

1. A double line of rails is used.
2. The rope rests upon the tubs, which are attached to the rope either singly or in sets of tubs varying in number from two to twelve.
3. The connection between the tubs and the rope is effected by a short chain, which is secured to the rope in a way hereafter described.
4. As with the endless chain, the tub or tubs are placed at a regular distance apart, and the rope is driven at a slow speed.
5. Motion is given to the rope by large driving pulleys, and friction is obtained by taking the rope several times round the driving pulley.
6. Curves can be worked by this system.

There are no instances of branches being worked by this method of conveyance, but, as will be seen by the following descriptions, this could very easily be arranged for.

Bridge Pit, near Wigan.—The No. 2 endless-rope system has been at work at this colliery about three years, and is here more extensively applied than at any of the collieries in the district.

The engine working the planes at this pit is a double 20-in. cylinder horizontal engine, with a stroke of 3 ft. 6 in.; the boilers are underground, at a distance of 150 yds. from the engine. Unlike the general adaptation of ropes in this district, the ropes on the planes are worked by a main driving rope, motion being transmitted by having two pulleys on one shaft. This was necessitated by the distance of the engine from the point to which the coals are led. The rope is driven by a main pulley, 14 ft. diameter, working on the third motion. The ratio of the strokes of the engine to the revolutions of the pulley is as 7·4 to 1.

DIMENSIONS OF ENGINE, BOILERS, AND ROPES.

Engine erected 1863.		
Number of cylinders	2	
	ft.	in.
Diameter of cylinders	0	20
Length of stroke	3	6
Diameter of piston-rod	0	3
Length of connecting rod	10	6
	in.	in.
Dimensions of steam-ports	18½ × 1⅛	
" exhaust "	18½ × 2¼	
	Steam. ft.	Exhaust. ft.
Length of breech-pipe	9	9
" main pipe	450	390
	in.	in.
Diameter of breech-pipe	5	6
" main pipe	6	7
	ft.	in.
Diameter of driving pinion	3	10
" follower	7	5
" fly-wheel (1)	10	3
" driving wheel	14	0
Distance between centres of cylinders	7	10½

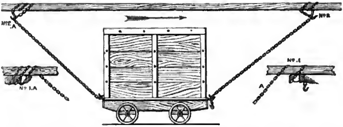
Boilers ..	Number	2	
	Description	Double tubular	
		ft.	in.
	Length over all	30	0
	Diameter	6	6
		Main. yds.	Tail. yds.
Driving Rope	Length	787	4730
		in.	in.
	Circumference ..	3·9	3·14
		cwts. qrs. lbs.	cwts. qrs. lbs.
	Weight ..	48 0 32	175 2 26
		months.	months.
	General duration ..	24	14
Sheaves ..	Number (between main pulley at engine and tightening pulleys) ..	34	35
		in.	in.
	Diameter	14	14
		lbs.	
Return Sheaves	Weight	672	
		ft.	in.
	Diameter	5	0

Description of Engine-plane.—These planes are laid with round-topped bridge rails in 12-ft. lengths, weighing 18 lbs. a yard. All the planes are laid with a double line of way, one line for the ingoing empty tubs, and the other for the full tubs coming out. The general size of the wagon-way is 10 ft. by 4 ft., it having been originally made this size. The average gradient of all the ways together is a rise towards the shaft of 1 in 62, the chain-brow way being a rise to the shaft of 1 in 54, the slant way a fall towards the shaft of 1 in 47, part of it at the inbye end rising towards the shaft at a gradient of 1 in 5·5.

With the exception of the curve on the chain-brow way, all the planes at this colliery are quite straight.

Method of Connecting the Tubs to the Rope by Chains.—The chains by which the tubs are attached to the rope are of ⅜-in. iron, 6 ft. long, with a hook at each end. They are connected to the tub as shown, Fig. 3931. The fore end of the tub is first connected to the rope; this is done by attaching one end of the chain to the second link of the coupling chain of the tub, and throwing the other end over the rope, which is constantly in motion. The chain is then passed twice over the rope, the hand being introduced under the rope to receive the coils, in order to let the chain slide loosely on the moving rope till the hook is secured. When the right number of coils of chain (two in this case) have been passed over the rope, the hand is withdrawn, the point A is brought over the hook, and the chain is pulled tight; it is not until the chain is securely fixed that the weight of the tub is allowed to come upon the chain. The sketch (No. 2) shows the chain just when it has been passed over the hook. When the full weight of the tub is upon the chain, the coils get quite close together and form a very compact and secure fastening. An expert hooker-on does not need to put his hand between the coils, but passes the chain round the rope, and secures it before the rope has time to move on. The chain at the back end of the tub is attached in a similar way to that described above, but with three coils instead of two; this is necessary at the Bridge Pit, owing to the heavy weight of the tub upon the chain for a short distance in going inbye. The tubs on the other planes at this pit are attached in a similar manner. When two or more tubs are put on the planes together, chains are fixed on to the fore and back ends of the gang, or at one end only, as the case may be. The chain is disconnected from the outcoming tubs, at the back end, by unhooking the chain from the tub; it is then easily loosened from the rope. At the fore end the chain is tight, and the foot is placed upon it, pressing it down, and making it loose enough to admit of disconnection. There is more labour required in the disconnecting than in the attaching at this pit. This description has reference to the taking off of the full tubs at the end of the main road, and here there is a rise towards the shaft. At some other places the terminus of the full way is made to dip slightly, and the chains are removed just when the tub, passing over the brow, loosens the chain at the fore end. On the other hand, the labour required for attaching the empty tubs is less than at other places; here the empty way is made to rise slightly, the fore chain is put on first, and one boy is able to manage both. At another pit (No. 5 Moor), where the empty way, at the start, falls inbye, both chains have to be put on together, thus requiring two boys.

3931.



At the top of the main-road way at the Bridge Pit, a boy stands about 20 yds. from the place to which the full tubs come, and removes the back chain, leaving it hanging on the rope by the hook; it is taken off by the man who disconnects the chain at the fore end, and, together with the other chain, is thrown over by him to the place where the empties are hooked on.

The usual time for attaching both chains to the empty tub is about twelve seconds, the minimum time being six seconds, and the time for disconnecting is rather more. Sometimes a stoppage is caused by the fastening of the chain being difficult to disentangle, and the man disconnecting has then to rap to stop the engine, to prevent the tub from reaching the pulley.

The chain is very seldom known to slip on the rope; when it does, the damage done is often rather heavy, since, should the fore chain slip, the tub going on to the back chain is generally upset, or in the absence of the back chain it may rest on the plane till the next tub comes up to it, the chain of which not only often knocks the tub off the way, but is sometimes broken itself, and as it is difficult to tell at the engine when such an occurrence takes place, there is much damage done before the engine is stopped. The chief accidents to tubs usually occur at the heavy gradient on the main way at this pit, for should a weak link in the connecting chain break whilst the tub is on this gradient, the tub getting loose generally breaks several other chains and tubs below it.

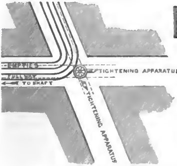
The slow speed at which the tubs go—being 1·35 mile an hour on the main road, and 1·126 mile an hour on the other ways—is necessary to prevent accidents to the tubs. The rope rests upon the tubs, and unless the way is laid perfectly straight, it is a slight distance from the centre of the tub; a small angle at a joint of the rails is sufficient to cause this deviation, and should the rope catch any irregularity on the top of the tub, it will sometimes overturn it; to avoid this, much attention is paid to keeping the tubs in good repair, and this partly accounts for the heavy cost of maintaining tubs at this pit.

In the working of the endless rope at this colliery the apparatus for putting the driving wheels in and out of gear is found to be indispensable. Thus the chain brow, the main road, and the main road with the slant way, can each be worked separately; the workings at the inbye end of the main road serve to keep the main way supplied for a short time, when it is necessary to put the slant way out of gear.

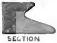
There are two curves on the engine-plane at this colliery, one at the bottom of the main road worked by disconnecting and reconnecting the tubs, and the other which self-acts on the chain-brow way. At the former, which turns round an angle of 72°, the motion is transmitted from one pulley to another on the same shaft, as shown, Fig. 3932. The road is laid round the curve at such an inclination that the full and empty tubs when disconnected run by themselves to the place where they are again attached to the rope. There are five bands required here, four boys and one man.

This curve might probably be made to self-act, like the curve at the chain-brow way, by means of four or more pulleys, but when it was originally arranged, it was intended to draw a large quantity of coals from other districts besides the slant way.

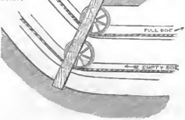
3932.



3934.



3933.

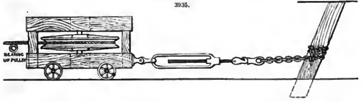


The curve on the chain-brow way is, as before described, of about 5 yds. radius, and at an angle of 118°, Fig. 3933. The ropes are taken round by two 4 ft. 6 in. pulleys, each inclining slightly towards the coming-on side. The way for the full tubs is laid nearly level, and for the empty a slight rise from the shaft; this arrangement, after many experiments, having been found to act most efficiently. The pulley wheels are made with a large flange on the lower side, Fig. 3934, to prevent the rope slipping off, and to enable the knot of the chain connecting the tub to the rope to pass easily into the trod of the wheels. The use of four pulleys instead of two at a curve of this description would enlarge the radius of the curve, and cause a smaller part of the surface of each wheel to be touched by the rope. Slow speed appears very necessary for working a curve by this system, for the jerk, which occurs when the tub, in passing round a curve, starts away after being stationary for a moment, would probably not fail to cause an accident if taken round at a much higher speed. A boy, placed near this curve for the purpose of taking off the chains at the fore end of the ingoing tubs, also attends to the curve when necessary.

Near the inbye end of the slant way there is a flat at which the tubs are taken off and put on, whilst the tubs passing to and from the terminus are in motion. The place is laid with flat sheets for a few yards, nearly on a level with the rails. The empty tubs are disconnected, and brought under the rope between two outcoming sets of full tubs. Points are laid on to the full way, and a full set or gang of two or more full tubs is put on, when the slackness of the rope indicates a long distance between two full sets.

Apparatus for Tightening Ropes.—The tightening pulleys, as used in this system of conveying small sets of one or more tubs by the endless rope, are fixed, and not similar to those used for the No. 1 endless rope at Shireoaks and other places, where the varying strain upon the rope, owing to the set of tubs being at different parts of the plane, makes it desirable to have the tightening apparatus movable.

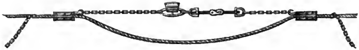
3935.



The pulley is fixed on a strong timber frame, to which a screw is attached. The screw is secured by a chain to a balk placed upright, see Fig. 3935. It is doubtful what strain is the effect of these tightening screws, but the engineer gives the following as what he estimates to be about the strain exerted.

Experiments with Dynamometer.—In making these experiments the dynamometer was attached by fixing clams to the rope about 4 yds. apart, and connecting the dynamometer by means of chains, Fig. 3936, to these clams; a screw was then applied to tighten the chain till the weight of the load upon the plane was wholly on the dynamometer.

3936.



The experiments were made upon the main road, the slant way and chain-brow way being put out of gear. As it was not considered safe to take the instrument upon the heavy gradient, it was tried only upon the level part of the main road, and was first taken 297 yds. inbye on the empty side, and then back on the full side.

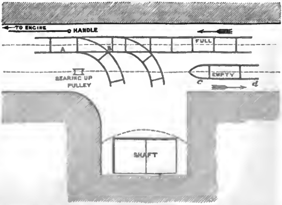
The engine was kept at the uniform speed of thirty strokes a minute, being the speed at which the experiments with the indicator were made. It was found very difficult to get the same number of tubs upon the plane as when experiments were made with the indicator. In going inbye there were forty-eight full and forty-four empty tubs upon the level part of the main road, and sixteen full and fourteen empty tubs upon the gradient of 1 in 5·5. In coming towards the shaft there were forty-eight full and fifty-eight empty tubs upon the level part, and twenty full and sixteen empty tubs upon the heavy gradient.

The readings of the dynamometer at each point, given below, are the averages of the maximum and maximum readings, the pointer often oscillating to the extent of 10 cwt.

ABSTRACT OF EXPERIMENTS WITH DYNAMOMETER.

Going Inbye.					Coming Outbye.				
Series.	Time.		Reading of Dynamometer.	Speed. Miles an hour.	Series.	Time.		Reading of Dynamometer.	Speed. Miles an hour.
	h.	m.	cwt.			h.	m.	cwt.	
A	11	7½	9	1·35	A	12	0	46	1·35
					B	11	59	44½	1·35
C	11	10	9	1·35	C	11	58	43	1·35
					D	11	55½	40½	1·35
E	11	12	9	1·35	E	11	52	38½	1·35
					F	11	50	34½	1·35
G	11	14	9	1·35	G	11	47½	..	..

3937.



No. 5 Moor Pit, near Wigan.—The coals are led at this pit under very similar conditions to the Meadow Pit. There is only one plane, which is in a direct line from the engine, the gradient being almost a regular rise towards the shaft. The length of the plane is 980 yds., and the average gradient 1 in 13. The plane is worked by a double horizontal engine, having 12-in. cylinders and 2-ft. stroke. The driving wheel is 6 ft. in diameter, and is on the third motion. The ratio of the strokes of the engine to the revolutions of the driving wheel is as 14 to 1; and as the engine goes about seventy-four strokes a minute, the speed of the tubs upon the plane is about 1·7 mile an hour.

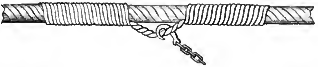
In the working of this engine road, the arrangement most worthy of note is that the braking of the engine is attended to by one of the hookers-on, by means of an iron rod, which extends from the engine to the terminus of the plane. The engine stands about 50 yds. from the plane, and is stopped in a moment when required.

There is a slight rise inbye about half-way along the engine-plane, and this necessitates the use of two chains for attaching each set of empty tubs; but as at the Meadow Pit, the heavier load of the full tub keeps the fore chain constantly tight, so that only one chain is needed in coming outbye. The chains at the fore ends of the empty tubs are taken off when the rise referred to commences, and are placed upon the out-going full tubs, Fig. 3937. The full tubs are put on two at a time, and empty tubs in sets varying from one to five tubs.

Scot Lane Pit, near Wigan.—At this pit an incline, 438 yds. in length, rising towards the shaft at an average gradient of 1 in 9, is worked by the endless rope.

The method of connecting the tubs to the rope at this pit is different to that in operation at the Bridge and other pits. Instead of the connecting chains being passed round the rope and thus secured, strong loops of hemp are fastened on to the rope by a wrapping of string, at regular distances apart. One hook of the chain is first attached to the tub, and the hook at the other end is then passed through the loop, as shown in Fig. 3938.

3938.



The tubs are sent along the plane one at a time, and as the gradient of the plane is very regular, only one chain is necessary for each tub. The heavy inclination causes the tubs to keep a constant weight upon the chain; on a light gradient the hook would probably be very liable to slip out of the loop. These loops are made of hemp, 1 in. in diameter, and last about four months; they are strong enough to draw twelve tubs at a time up the plane. They are fixed on to the rope, 17 yds. apart, thus making a regular supply of full and empty tubs necessary. Much less labour is required on connecting the tubs to the rope by this arrangement, but it would scarcely be so applicable on an irregular plane, where two loops would have to be provided for each tub or set of tubs. Although the rope passes 1½ times round the driving wheel, the loops are formed to pass round without causing an inconvenience.

South Wales Endless-chain System, Brynddu Colliery, Glamorganshire.—Since the first part of this Report was printed the above colliery has been visited, and as the mode of conveying coals is unlike any before described, and as it is peculiarly adapted to the circumstances under which it is applied, it is thought desirable to give a short description of this method of working the endless chain.

DIMENSIONS OF ENGINE, BOILERS, AND ROPES.

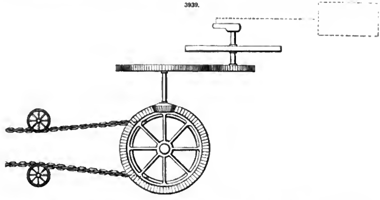
Engine erected 1858.			
	Number of cylinders		1
	Diameter of cylinders	ft. in.	2 1
	Length of stroke		4 5
	Diameter of driving wheel		10 3
	Consumption of coal a day	tons.	4
Boilers	Number		3 on surface 1 underground
	Description		Cylindrical
	Length over all	ft. in.	30 0
	Diameter		6 0
Chain	Diameter of iron	in.	1¼
Chain	Length of link	in.	7
	Weight	cwt.	440
	General duration	months.	16
Rails	Weight a yard	lbs.	25
	Length of each	ft. in.	9 0
	No. of lines		4
	Gauge of ways		2 6
Tubs	Average weight (empty)	cwt.	10
	" " of coal contained		15
Work Done.	500 tons a day of 10 hours.		

Description of Engine-plane.—The plane on which the chain is used is 600 yds. in length, and descends at the heavy gradient of 18 in. a yard from the shaft. The engine for hauling the coals up this incline is placed on the top of the plane, and works the chain by a horizontal driving wheel. The ordinary speed of the engine is about forty strokes a minute. The chain used is made of 1¼-in. iron, and has links 7 in. in length. The engine is horizontal. The arrangement of gearing for giving motion to the driving wheel will be seen in Fig. 3939.

The chain runs on rollers, which are placed 75 ft. apart. The connection between the chain and the tubs is made by a short chain 2 ft. 6 in. in length, made of ¾-in. iron, with an ordinary hook on each end. A tub attached in this manner to the chain is shown in the sketch, Fig. 3939. Only one tub is put on at a time, the distance between each tub being about 50 yds.

There are eight stations on the plane, at each of which the empty tubs have to be delivered, and full tubs brought away. This is done by a simple arrangement. Two long balanced arms, which are usually parallel with the roof of the wagon-way, are drawn down to the level of the way when the tubs have to be put off or taken on at any station. The arms when brought down are level, and are so regulated by the counterbalance, and the weight hanging over the pulley,

3939.



as to be very easily moved. There are two arms at each station for both empty and full ways, and these are supported by a beam across the wagon-way. Between each two arms an iron plate is laid, on to which the tub runs when disconnected from the chain; the tub is then turned on the plate, and taken into the station. The chain travels at the rate of two miles an hour, and at this speed the tubs can be easily connected and disconnected at the stations, without stopping the engine.

In attaching an empty tub at the top of an incline, the tub is brought close to the commencement of the incline, and the short chain is connected to the tub in the first place, and then to the chain, and immediately after the last connection the tub is pushed forward on to the incline; when the full tub comes to the top of the incline, the chains are disconnected just at the time when the tub coming on the level takes the weight off the short chain.

Considering the very exceptional character of the conditions under which this system is worked, and its singular adaptability both to the heavy gradient and to the leading of coals from numerous stations, it is probably the most economical arrangement which could be here adopted.

Extracts from the Summary of the Report of William Cochrane, George B. Forster, John Daglish, Lindsay Wood, R. F. Matthews, Acting Members of the Tail-rope Committee; Emerson Bainbridge, Engineer to Committee.—It would be difficult for the committee who present the foregoing Report on Underground Haulage to recommend for general use any one of the systems reported on, since each is peculiarly, and advantageously, applicable to one condition or more of wagon-way; it was therefore thought desirable to take a general view of each of the systems, and endeavour, by considering their respective advantages, to give some idea of their comparative worth under the various conditions in which they exist.

Tail-rope System.—This system of conveying coal underground is most largely developed in the counties of Northumberland and Durham, where, after many years trial, it has now attained a high degree of perfection.

One of the leading features of the tail-rope system is, that it can be applied under almost any condition of wagon-way, the crookedness of the way, irregularity of gradient, and numerous stations and branches, forming no obstacle to its effective working.

On a single road the tail rope is generally applied:—

1. When the gradient of wagon-way dipping inbye is not sufficient to cause the empty tubs to draw a single rope after them.

2. When the gradient dipping outbye is insufficient to make the tubs self-act.

3. When, as at North Hetton, the full tubs coming outbye will not pull the single tail rope after them.

This single tail rope (that is, a tail rope working without a main rope) is in operation in the main coal seam at North Hetton Colliery, where the engine-plane rises from the shaft, and the rope passing round a sheave at the inbye end of the plane, draws the empty tubs up the bank, the full tubs being braked down. This arrangement is usually adopted when the tubs will not self-act, and where it is desirable to have the engine near the shaft.

The tail rope is usually applied on branches to supersede horses.

The following are the conditions of the five tail-rope planes reported on:—

North Hetton—Two main roads, with branches worked both to the rise and to the dip, and with curves on the main road and on the branches.

Seaham—Engine-plane, with slight curves, rising towards the shaft.

Seaton Delaval—Engine-plane, with slight curves, level.

Harraton—Engine-plane, with sharp curve, falling towards shaft; one branch worked.

Murton—Engine-plane, with curves, rising towards the shaft.

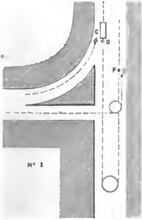
Methods of Applying the Tail-rope System.—The arrangement of engine and appliances for working the tail-rope system usually consists of an engine with two drums, worked on the second motion—the drums being either on different shafts, and put in and out of gear by shifting carriages, or on the same shaft, clutch-gear being then used for connecting them with the engine. One drum is used for the main rope, and the other for the tail rope. At the inbye end of the main road, and of each of the branches from the main road, there is a sheave round which a tail rope passes, both ends of which, when used on the branches, are brought to a station on the main line; when only one way is worked, one end of the tail rope is brought up to the station, whilst the other is attached to the tail drum. In taking a set of tubs, which usually numbers from thirty to sixty, inbye, the tail-rope drum is connected to the engine, and in coming outbye, the main-rope drum; in going both inbye and outbye, the brake is gently applied to the loose drum to prevent the dragged rope from becoming too slack.

When two wagon-ways are worked in opposite directions from the engine, four drums are generally used, there being then a main and tail rope for each way.

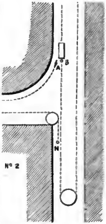
Curves can be worked by the tail-rope system at any angle and at a comparatively small radius. The curves at North Hetton, of 22 yds. radius, have perhaps the minimum radius at which curves can be made to work safely. The fact that the sets pass round these curves at the rate of ten miles an hour, and that an accident very rarely happens, is sufficient proof of their efficient working. The sheaves (3 ft. diameter) used at the Harraton curves are doubtless the means of economizing the power, and effecting a considerable saving in the wear and tear of the rope.

In working branches by this system there are three methods of attaching the branch-rope ends to the main rope; these will be seen by the sketches, Figs. 3940 to 3942; in Figs. 3940, 3941, the ropes are changed when the set of tubs is near to the branch end, but Fig. 3942 shows the set at the shaft.

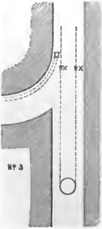
3940.



3941.



3942.



In Fig. 3940 a wheel is fixed near the roof or under the rails, round which one end of the branch rope passes. When the incoming set has to go into the branch, the rope end C replaces D on the fore end of the set, and the end E replaces F on the tail rope.

In Fig. 3941 the tail rope always remains entire; the end A replaces B, and the end B of the rope is brought a little farther by the engine, and is then attached to N. This method of attaching the ropes, which is in operation at Murton East Pit, can be worked without a winch, which is generally necessary in Fig. 3940.

In changing the ropes by method, Fig. 3942, a very different course is pursued. When a set is taken outbye from any station to the shaft, the boy at one of the branch ends changes the ropes, whilst the ropes at the shaft are being attached to the empty set. The position of the ropes is so arranged, that when the set reaches the shaft, the shackles on the main and tail ropes are just opposite each other at each branch end, as shown on sketch, when the rope ends X X are replaced by Y Y.

This plan is much more expeditious than either of the others, since in Fig. 3942 no time is lost in changing the ropes, as they are generally ready at the branch end before the set is ready at the shaft; but in the other methods, another stoppage, in addition to the time required to change the ropes at the shaft, is necessary.

At Harraton, the method, Fig. 3940, of changing the ropes is preferred; there is only one branch at this colliery, and they bring out such a large quantity of coal from the two ways, that till the empty set has had time to get to the switches, it is difficult to tell which of the ways is ready for it. It would thus appear that when few branches are worked, and a large quantity of coal is brought out, No. 1 or No. 2 method of changing the ropes is preferable to No. 3.

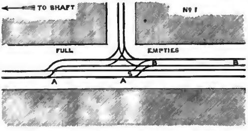
The labour at a branch end can be managed by one boy; when Nos. 1 and 2 methods are adopted, a *run-rider* is of some service, as two connections have to be made, and at points often some distance apart; with No. 3 method a run-rider is not so necessary, but is generally employed. When two branches are worked opposite to each other the same amount of labour is sufficient. Run-rider is the name given in the North of England to a man or boy who rides on the last tub of the set, for the purpose of signalling to the engineman in case of an accident; he also assists in connecting the ropes to the set.

Three methods of taking the ropes round curves will be seen on the sketches, Figs. 3943, 3944. In No. 1 the curve has a large radius, and the tail rope is taken round a single sheave, and along a narrow place, a pillar of coal supporting the roof between it and the curve. The curve in No. 2 is of less radius, and no pillar is left. In No. 3, which is generally adopted on very short curves, instead of taking the tail rope round a single sheave, both ropes are taken round the curve by a number of sheaves.

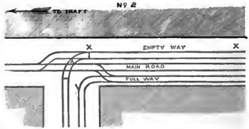
The tail rope is often applied to work a plane with no branches, but with one or more stations on each side of the main way, in which case only one set of ropes is used. Murton and Seaham planes present examples of this arrangement. These stations are usually worked by one of the two methods shown, Figs. 3943, 3944.

In No. 1, which represents the arrangement of the North Hetton stations, the ropes are knocked off the empty set in going in at the points A A, opposite to which the full set stands ready to go out. A gentle fall in the way causes the empty tubs to run forward, and they are turned by the switch S into the siding B B.

3943.



3944.



In No. 2, which shows the Seaham Colliery arrangement, the middle way is the main road; the empty tubs, having been brought into the siding X X, are then brought round the curve A, which consists of two movable rails. When the full set comes out these rails are removed. With this arrangement the drivers have to cross the main road every time they take the empty tubs inbye; this is avoided with the stations worked as at North Hetton.

The engine and boilers requisite for working the tail-rope system are usually arranged in one of the three following ways:—

1. The engine and boilers both on the surface, the rope being taken down the pit in wooden boxes.

2. The boilers on the surface, and the steam-pipes taken down the shaft to the engine underground.

3. The engine and boilers both underground.

Endless-chain System.—The experiments on the endless-chain planes, which follow next in order to those on the tail-rope planes, were all made at the collieries at Burnley, under the management of Mr. W. Waddington.

Although the endless-chain system of leading coals has been in operation at Burnley, and other parts of Lancashire, for a great number of years, it has until lately been very little known in the North of England.

Like the tail-rope, the endless-chain system is adaptable to every condition of wagon-way, but differs from the former system in the following important items;—

1. As a general principle, it may be stated that when the two ends of an undulating plane are at the same level, the power required to work such a plane will be very little more than if the plane were perfectly level.

2. A heavy gradient can be worked safely and efficiently.

3. Since the chain will only work safely in a straight line, or, at the most, round a slight curve, every sharp curve upon the planes necessitates the erection of two pulleys, in order to direct the chain to another course, and requires the attention of a man or boy.

The system is very extensively in operation on the surface at Burnley, and the slow speed at which the tubs are conveyed not requiring a very carefully-laid wagon-way, they generally lay the way upon the uncut sod, only making embankments or erecting gearing when a stream or deep dodlo has to be passed over. The surface of the country is very hilly in this district, and it is therefore more economical to carry the coals from the pits to the canals and railways in tubs by the endless chain, than by wagons on ordinary railways.

The endless-chain planes reported on are as follows;—

Hapton Valley.—Underground chain road.
" " Surface chain road.
Gannow, top bed.—Underground chain road.
" low bed.— " "

Rowley.—Underground chain road.
" Surface chain road.
Clifton Hall.—Surface chain road.

Methods of Applying the Endless-chain System.—The engines working the endless chain at Burnley are nearly all of one class, namely, double 12½-in. cylinder vertical overthrow engines. Motion is transmitted to the wheel driving the endless chain by means of toothed gearing; the engine usually goes at a speed of about eighty strokes a minute, and works the driving wheel on the third motion.

The engine-plane consists of two lines of rails, one for the full, and the other for the empty tubs, the tubs moving in opposite directions. The lines are generally laid just near enough together to allow a few inches play between the tubs on the empty and full ways.

In working a straight main way (that is, with no branches), such as the Rowley and Hapton Valley surface planes, by the endless chain, the driving power is generally placed at the higher end of the ginney road. The only wheels requisite for working the chain are the driving wheel at one end, and a tail or return sheave at the other end of the plane; between these two points the chain rests upon the full and empty tubs, the distance of which apart, and the speed at which they are moved, vary according to the quantity of coal passing along the plane, the distance between the tubs being from 10 to 30 yds., and the speed from one to three miles an hour.

The wheels round which the chain passes at the two ends of a ginney road are usually 3 ft. in diameter. The driving wheel, as used at Burnley, generally consists of an ordinary sheave, round which a piece of boiler-plate, about 10 in. wide, is fixed, and to this are attached about twelve steel or iron feet, on which the chain rests; these feet are renewed, as required, and thus the chain never touches the plate. The method invariably adopted at Burnley, in order to get friction sufficient on the chain to prevent it slipping round the driving wheel, is by passing it 2½ times round the wheel; at Towneley Colliery it is passed 4½ times round. At the Baxenden Collieries, near Newchurch, ordinary sheaves, with forks about 12 in. apart fixed in the trod, are used as driving wheels, the chain only passing half a turn round, and the horizontal link of the chain fitting into the fork. These wheels, which are much preferred at Newchurch, were formerly used at Burnley, but are now altogether abandoned in favour of the bevel-faced wheels. The return wheels, at the other end of the ginney road, are just common 3-ft. sheaves, round which the chain passes half a turn.

When there is a curve in a single chain road, either the same chain is taken round the curve by two wheels on different shafts, arranged like the self-acting curves on the surface, or there are two pulleys on the same shaft on which are different endless chains. If there be no branch way from the curve, the former method is usually adopted, and the road is so formed that the tubs will leave one chain, pass round the curve, and connect themselves to the other chain, without any assistance; but as this cannot be depended upon, attention is always necessary at a curve. At the Burnley Collieries there is generally a branch end at every curve.

There are only two self-acting curves in the Burnley district, both of which are on the surface. These curves generally work very well, and without the occurrence of any accident; but as a badly-greased tub, or a tub getting off the way, causes some damage, if not looked to, they are always kept in sight, that at Padiham being within a few yards of a man constantly working at the same place, and that at Towneley within view of the terminus of the ginney road. With very carefully-laid rails, and due attention to the exact point at which the rise or fall of the way should be, curves might be worked at almost any angle, and with very little attention.

As far as hitherto proved, it may be laid down as a rule in the working of the endless-chain system, that all curves underground require labour, and thus it is generally desirable either to have a branch or branches from the curve, or to pass the tubs round by the self-acting method described, which could be managed by a boy at 1*s.* a day. It has yet to be shown to what extent curves can be worked by this system without pulleys. At the Baxenden Collieries, in Lancashire, a curve of about 15 chains radius has lately been commenced on the surface, and is found to work very satisfactorily.

In working branches the chain passes round a wheel at the branch end, which transmits motion to another pulley or pulleys, either on the same shaft, or on another shaft a short distance off; when the pulleys are on another shaft, motion is given either by mitre-gearing and shafting, or by a short endless chain; at Towneley motion is transmitted by continuing the same chain past a branch end, and taking it over a pulley which works the branch by means of vertical gearing. The pulleys on the main road for working the branches are generally so arranged, that they can be put out of gear, in case of any accident or slackness of work, whilst the other chains continue in motion.

Though it would appear rather difficult to work a branch on each side of the main way to the same point, since the full tubs from one of the branches cross over the course of the empty tubs on the main way, and the empty tubs from the other branch cross the course of the full tubs, the slow speed at which the tubs travel prevents this from causing any inconvenience.

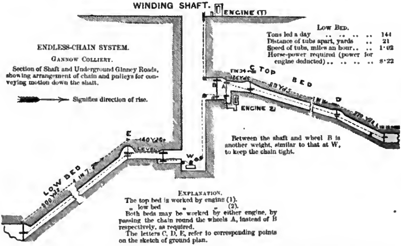
Another mode of working branches is that carried out at Marsden Colliery, near Burnley, where two branches are worked by one chain passing round a single pulley. This is the only one of all the methods of working branches, in which one branch cannot be put out of gear without stopping another.

In each of the arrangements mentioned for working branches, it is necessary that the tub should leave the chain at the station—becoming attached to it again immediately beyond the pulley; and the attending to the re-attaching of the tubs at the branch ends in this way, is one of the chief items of labour in the cost of leading coals by the endless chain. The mode of working branches usually adopted at Burnley, is to have shafting and mitre-gearing under the flat sheets, sometimes, as at Hapton Valley, working two branches from the same mitre-wheel.

In working branches by the endless chain no regular curves are necessary, since at the branch ends the termini of ginney roads are usually laid with flat sheets upon which the tubs are turned; the small tubs used at Burnley can be turned so quickly, that there is often not more than 10 ft. from the end of one ginney road, to that of another at right angles.

At Gannow and Rowley Collieries the underground endless chain is worked by an engine on the surface, the chain at the latter colliery being attached to the winding engine. The way in which the chain is conveyed down the shaft is very simple, and is shown in the section of the Rowley and Gannow underground planes, Fig. 3945. Whilst a $\frac{5}{8}$-in. chain is used in the workings, a $\frac{3}{4}$-in. chain is used in the shaft, the latter being usually kept tight by passing the chain, at the bottom of the pit, round a sliding pulley, to which a suspended weight is attached. A sufficient proof of the efficient working of the chain in the shaft, and of the very small amount of power requisite to take it down the pit, is given by the results of the Rowley experiments, which show that only 0·54 horse-power is required to take the chain 150 yds. down the shaft, and 27 yds. from the bottom of the shaft to the main driving wheel.

3945.



ENDLESS-CHAIN SYSTEM.

GANNOW COLLIERY.

Section of Shaft and Underground Ginney Roads, showing arrangement of chain and pulleys for conveying motion down the shaft.

→ Signifies direction of rise.

Low Bed.	
Tons led a day	144
Distance of tubs apart, yards ..	21
Speed of tubs, miles an hour.. ..	1·02
Horse-power required (power for engine deducted)..	8·22

Between the shaft and wheel B is another weight, similar to that at W, to keep the chain tight.

EXPLANATION.

The top bed is worked by engine (1).
" low bed " " (2).
Both beds may be worked by either engine, by passing the chain round the wheels A, instead of B respectively, as required.
The letters C, D, E, refer to corresponding points on the sketch of ground plan.

As compared with the tail rope, the maximum advantage of the endless chain, as far as the power requisite to drive the system is concerned, is probably realized on an undulating plane, the ends of which are at the same level. A very good instance of the counterbalancing effect of an undulating road is shown on the Rowley plane, which is 1980 yds. long, the highest point on the plane being 145 ft. above the lowest, and the average gradient 1 in 68, fall for full tubs; here only 5·16 horse-power is required to work all the tubs, and chain suspended on the tubs. Another instance is at Rowley Colliery, where the average gradient of the planes is sufficient to cause all the tubs to self-act. The planes at this colliery, however, are kept connected to the engine for reasons explained in the report on the Rowley plane.

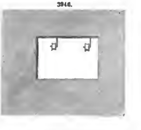
The chief feature of the self-acting planes, as worked by the endless chain, is that *a regular gradient is unnecessary*, a heavy dip at one part of the plane being sufficient to cause the tubs to self-act. Thus a plane may have a rise for some distance for the full coals, and yet, since there is continually a load upon the heavy part of the plane in favour of the full tubs, self-act. Thus planes can self-act by the endless chain which could not possibly do so with a rope.

At Burnley, the force of gravity on self-acting planes is sometimes made to work a level plane at the top of the self-acting plane.

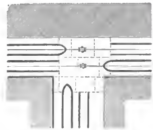
Stations are worked by the side of the main chain roads, simply by having small pulleys fixed to the roof, Figs. 3946, 3947, opposite to the station, on which the chain is placed when tubs are required. There are generally iron flat sheets at the stations over which the tubs are brought from the opposite side of the way. A tub, after having been passed over the flat sheets, is allowed to be altogether moving on the rails again before it is touched by the chain, in order that the chain may be sure to reach it in the centre.

The method of leading coals by the endless chain as adopted at Clifton Hall Colliery, which consists in moving the tubs by the weight of the chain alone, there being no forks on the tubs, can only be recommended when the plane to be worked is level or nearly level, and where the system is not extensively applied.

3946.



3947.



Endless-rope System.—This system of conveying coal is closely allied to the tail rope, but has hitherto been adopted in the working of underground planes, only to a limited extent.

The following planes, the conditions of which are given on page 1862, are reported on, and present four distinct methods of applying the system;—

I.—Shireoaks Colliery—Engine-plane, with double way, worked by rope at quick speed, the tubs being attached to the rope in sets, by a clamp.

II.—California Pit.

III.—Newsham Colliery—Engine-plane, with single way, worked by rope at quick speed, the tubs being attached to the rope in sets, by short chains secured to sockets in the rope.

IV.—Eston Mines—Three sidings, worked by the socket connection at slow speed.

V.—Cinderhill Colliery—Engine-plane, with double way, and sets of full and empty tubs running at the same time at slow speed, the sets being connected to the rope by clamps.

Experiments were made only at Shireoaks Colliery.

Methods of Applying the No. 1 Endless-rope System.—In the application of this system as adopted at Shireoaks and the California Pit, a double way is used, and the rope moves on rollers in the middle of the way, the set of tubs being taken in on one way and brought out on the other.

Motion is given to the rope either by a clip-pulley, or by several wheels, round which the rope is taken to obtain sufficient friction. The rope is kept constantly tight by having the return sheave fixed on a movable tram, to which a weight, hanging in a staple, is attached.

The set of tubs is connected to the rope by a clamp, which is held by a boy sitting in the foremost tub. Different descriptions of clamps are used; the clamp in use at Shireoaks differs in construction from that used on the California and Cinderhill planes. As these planes rise in one direction, only one clamp is employed; but were the planes undulating, two (one for each end of the set) would be required, and as this would make two men or boys necessary for each set, the use of the clamp, under these circumstances, would not be advisable.

The number of tubs in a set varies from twelve, on one of the California ways, to thirty-one at Shireoaks, and the speed at which the sets travel is about the same as with the tail-rope system.

The clamp is usually attached at the front end of the set, but on one of the California planes the gradient is heavy enough to allow the clamp to be applied to the last tub of the set, in going in; when, as occasionally occurs, the full and empty sets are run together on the plane, this assists the engine.

In the application of this system at Newsham and Eston, motion is given to the rope, which is also kept tight by a hanging weight, by the clip-pulley, as at Shireoaks, and the set of tubs is connected to the rope by means of one or two short chains, which are secured by means of a hook or screw-shackle to a socket in the rope. At Newsham, owing to the undulations of the plane, two chains attached by the screw-shackle are required, whilst at Eston, where the roads are short and level, the set is attached to the rope by a single chain, which is simply hooked on. The Eston arrangement is adaptable when there are numerous short sidings, and could probably be economically applied in the place of horses at collieries where there is a good deal of branch work. The plan at Newsham of having a single way, as with the tail-rope system, and of running one part of the rope on sheaves by the side of the way, is probably the best arrangement of the system, and that which, for the following reasons, may be expected under some circumstances to supersede the tail rope.

1. A driving wheel is used instead of two drums.
2. One-third less rope is required.
3. The power expended with the tail rope in overcoming the friction of the brake on the loose drum is utilized by the employment of a single wheel.

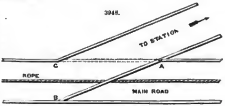
It has yet to be shown how far this system is applicable where curves, and the working of branches, have to be contended with. With the clamp connection a slight curve is worked on one of the California planes without any difficulty. No instances are known of curves occurring on wagon-ways where the socket connection is adopted, but in all probability they could be managed without much difficulty, the tightening of the rope being the only obstacle to their efficient working.

The slow motion of the rope, as worked at Cinderhill, would allow it to pass round curves of almost any radius. The system adopted at Cinderhill, which consists in having a double way, and in running the sets of full and empty tubs at the same time at a speed of 2½ miles an hour, cannot be recommended owing to the heavy cost of labour, each set being connected by a separate clamp which is attended to by a man or boy. Friction for driving the rope is obtained at this colliery by taking it round five wheels, and the rope is made tight by having two of the wheels placed on a movable carriage; with an undulating plane where the load varies, this method of tightening the rope would not answer.

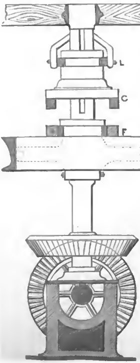
The chief defect of this endless-rope system, as far as hitherto developed, is its inapplicability to the working of branches from the main way, the tightness of the rope precluding the possibility of offtake links being used, as with the tail rope. A series of clip or friction pulleys, with disconnecting gear, might perhaps answer the purpose, but in this case, as the tubs could not go round the right angle without being uncoupled, the set of tubs would have to be disconnected from the rope, and sent by its own impetus round a curve into the branch way, where it would be attached to the branch rope. Of course this would only be possible under exceptional conditions of wagonway, and as considerable labour would be required were the socket connection adopted, the clamp would be the most economical mode of attachment.

Stations by the side of the main way might be worked by the system without much difficulty, but would require rather more labour than by the tail-rope system. At Shireoaks the rope at the station passes under the way, and when the ingoing set is intended for the station, the clamp is removed some distance from the points, and the set runs into the siding by itself. With this arrangement the set could not go any farther inbye, if attached to the rope, but, as

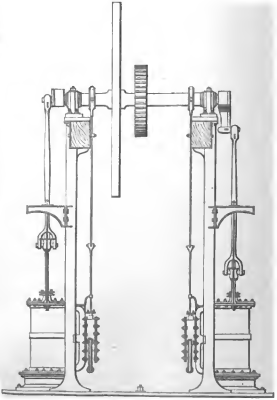
3948.



3949.



3950.



explained in the Shireoaks report, the set when going in is disconnected from the rope before reaching the station, and the inclination of the way is sufficient to take it to the end of the plane. It will thus be seen that on the Shireoaks plane, stations could not be worked under other conditions than those described. They might, however, be arranged like the tail-rope stations, Fig. 3943, and by having the points leading from the main way to the siding movable, as shown, Fig. 3948, the difficulty of the rope being endless would be obviated. Here the rail A B moves on a pivot at A, Fig. 3948; if the set had to go into the station, this rail would be placed as shown, the rope passing *under* the rail; if it were intended for the main road, the rail would be put into the position A B. More labour would be necessary in leading coals from stations in this way than is requisite with the tail-rope system, which is very well adapted for the purpose.

As this system is capable of conveying a large quantity of coals on a single way, the double way as adopted at Shireoaks may be considered quite unnecessary, and can only be recommended where sockets are used and run-riders dispensed with, and where the inclination of the engine-plane is such that one set of tubs will give assistance to another throughout the greater part of the plane.

Fig. 3949 is of an effective arrangement of driving wheel at Hapton Valley Colliery. Fig. 3950 is of the vertical double engine at Hapton Valley and Rowley Collieries. See AGRICULTURAL IMPLEMENTS, p. 29. BRAKE. COAL-CUTTING MACHINE. COAL MINING. COAL WASHING. DRAINAGE. DYNAMOMETER.

HAUNCH. FR., *Esselle*; GER., *Gewölbeschenkel*; ITAL., *Coscia della volta*; SPAN., *Riñon de una bóveda.*

That part of an *arch* between the key-stone and the springing is sometimes termed the haunch of an arch; the two parts between the crown and the springing are hence called the haunches of the arch. See ARCH.

HAWSER. FR., *Aussière, Grelin*; GER., *Tross, Schlepptau*; ITAL., *Gherlino*; SPAN., *Guindaleza.*

A hawser, or halser, is a small cable; or a large rope, in size between a cable and a tow-line. The sizes and lengths of hawsers and warps, according to Lloyd's Rules, are given in the following tabulated form.

Ship's Tonnage.	Hawsers and Warps.						Ship's Tonnage.	Hawsers and Warps.					
	Stream.			Hawser.	Warp.	Length.		Stream.			Hawser.	Warp.	Length.
	Chain.		Rope.					Chain.		Rope.			
tons.	ins.	16ths.	inches.	inches.	inches.	fathoms.	tons.	ins.	16ths.	inches.	inches.	inches.	fathoms.
50	0	7	5	3	..	90	600	0	13	9·5	7	4	90
75	0	7	5	3	..	90	700	0	14	10	8	5	90
100	0	8	5·5	3	..	90	800	0	14	10	8	5	90
125	0	8	5·5	3·5	..	90	900	0	15	10	9	5·5	90
150	0	9	6	4	..	90	1000	0	15	10	9	5·5	90
175	0	9	6	4	..	90	1200	1	0	10	9·5	6	90
200	0	10	6·5	4	..	90	1400	1	0	10	10	6	90
250	0	10	7	5	..	90	1600	1	1	11	10·5	6·5	90
300	0	11	7·5	5·5	..	90	1800	1	1	11	11	7	90
350	0	11	7·5	5·5	..	90	2000	1	2	11	11	7	90
400	0	12	8	6	..	90	2500	1	2	12	12	8	90
450	0	12	8·5	6·5	..	90	3000	1	3	12	12	8	90
500	0	13	9	7	..	90							

HEART-WHEEL. FR., *Roue en cœur*; GER., *Herzscheibe*; ITAL., *Ruota a cuore*; SPAN., *Rueda de corazon.*

See GEARING.

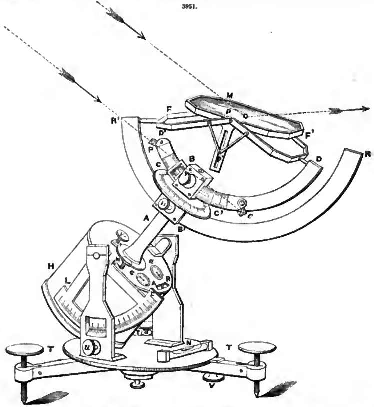
HELIOSTAT. FR., *Heliostat, porte-lumière*; GER., *Heliostat*; ITAL., *Eliostata*; SPAN., *Heliostato.*

A heliostat, Fig. 3951, is an instrument by which a sunbeam may be introduced into a dark room, and, by means of clockwork, kept directed to, and upon a fixed point. A heliostat, suitably arranged, is often employed in trigonometrical surveying. See GEODESY.

Silbermann's Heliostat.—This apparatus is mounted on a plate which moves round a vertical axle, and is adjusted by means of a level; the position of the axis of the time-piece is made to correspond with the latitude of the place by means of an arc and the adjusting mechanism *u*. Supposing now that this axis has been placed in the meridian and that C C′ represents the dial, D D′ a limbus, the centre of which is in O, and in the plane of which is carried a needle pointing to the correct hour indicated on the dial, then the plane of the limbus will pass through the centre of the sun. The limbus D D′, which moves in a box B, in which it may be fixed at any position by means of the screw V, is divided into parts, and by making the distance from the centre of the box to the end D of the limbus equal to the complement of the declination, the line D O M will represent the direction of the rays of the sun.

The mirror is carried by a jointed or articulated rhombus, the diagonal P P′ of which is vertical to the plane of the mirror; this rhombus is constructed in such a manner that one of its sides is parallel to D O, that is to say, parallel to the rays of incident, whence the reflecting rays become parallel to the other side of the rhombus. By means of a second limbus R R′, which can be fixed in its position by the screw V′, the inclination of these reflecting rays can be changed; and in order to bring these rays into all possible azimuths, the limbus R R′ is carried upon a hollow shaft A, which contains, besides the transferring mechanism of the time-piece, the moving mechanism for the needles and the other limbus D D′; this shaft A can be fixed by the hand-screw V″. A pinule *e* and a screen P are arranged in such a manner that the chord *e* P is parallel to O D, whence the ray that passes through *e* arrives always at P as soon as the apparatus is regulated. This circumstance or condition may be used, on the other hand, for placing the axis in the meridian by means of setting the time-piece correctly, making the arc B D equal to the complement of the declination, and by turning then the apparatus upon its base-plate until the ray of the sun is seen to pass from *e* to P. A similar arrangement is adopted in M. Foucault's heliostat, and may be fixed to all other ones. Fig. 3951 is of a heliostat made by Elliott Bros., London.

3951.



HELIX. Fr., *Hélice*; Ger., *Schraubenlinie, Spirale*; Ital., *Elice*; Span., *Hélice*.

A helix is a curved line of double curvature, a spiral line, as of wire in a coil. A knowledge of twisted surfaces, that have helices to guide the generating straight line, is indispensable in designing *screw-propellers*. The equations of the helix are $x = a \cos. \frac{z}{h}$ and $y = a \sin. \frac{z}{h}$; x, y, z, being the co-ordinates of any point in the twisted surface. See Archimedian Screw. Propellers.

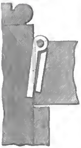
HINGING. Fr., *Ficher*; Ger., *Aufhänger, durils ein Gelenk verbinden*; Ital., *Gangherare*; Span., *Embisagrado*.

Hinging is the art of connecting two pieces of metal, wood, or other material together, such as a door to its frame; the connecting ligaments that allow one or other of the attached substances to revolve are termed hinges. There are many sorts of hinges, among which may be mentioned, butts, chest hinges, coach hinges, rising hinges, casement hinges, garnets, scuttle hinges, desk hinges, screw hinges, back-fold hinges, centre-point hinges, and so on. To form the hinge of a highly-finished snuff-box requires great mechanical skill; but few of the best jewellers can place a faultless hinge in a snuff-box.

There are many varieties of hinges, and hence there are many modes of applying them, and much dexterity and delicacy are frequently required. In some cases the hinge is visible, in others it is necessary that it should be concealed. Some hinges require not only that the one hinged part should revolve on the other, but that the movable part shall be thrown back to a greater or lesser distance. Figs. 3952 to 3998 exhibit a great variety of methods of *hinging*.

Fig. 3952 shows the hinging of a door to open to a right angle, as in Fig. 3953. Figs. 3954, 3955, and Figs. 3956, 3957, show modes of hinging doors to open to an angle of 90°. Figs. 3958, 3959, show a manner of hinging a door to open at right angles, and to have the hinge concealed.

3952.



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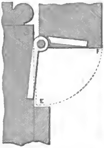

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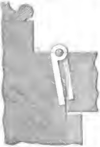

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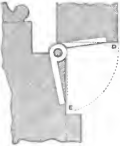

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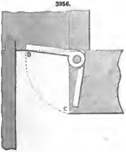

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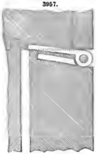

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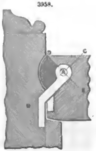

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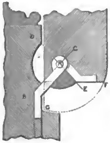
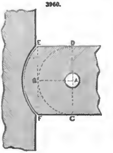
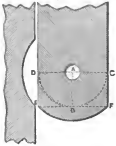


3960.



3961.



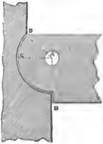
The segments are described from the centre of the hinge A, and light portion requires to be cut out to permit the passage of the leaf of the hinge A B. Figs. 3960, 3961, illustrate an example of a centre-pin hinge, the door opening either way, and folding back against the wall in either direction. Draw E F at right angles to the door, and just clearing the line of the wall, which represents the plane in which the inner face of the door will lie when folded back against the wall in either direction. Bisect E F in B; draw A B perpendicular to E F, which make equal to E B or B F, then A is the position of the centre of the hinge.

To find the centre of the hinge, Figs. 3962, 3963; draw A D, making an angle of 45° with the inner edge of the door, and A B parallel to the jamb, meeting D A in A the centre of the hinge; the door, in this case, will move through a quadrant D C.

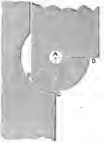
Figs. 3966, 3967, are of another variety of centre-pin hinging, opening through a quadrant. The distance of A from B C is equal to half B C. In this, as in a previous case, there is a space between the door and the wall when the door is folded back. In Figs. 3962, 3963, as well as in Figs. 3966, 3967, there is no space left between the door and the wall.

Fig. 3964; bisect the angle at D by the line D A; draw E C and make C F = $\frac{3}{2}$ D E; draw F G at right angles to C E, and bisect the angle G F C by the line B F, meeting D A in A; then A is the centre of the hinge. Fig. 3965 shews, when the door, Fig. 3964, is folded back, that the point C falls on the continuation of the line G F.

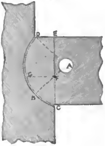
3962.



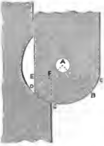
3963.



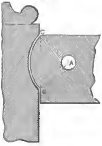
3964.



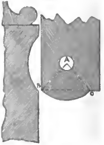
3965.



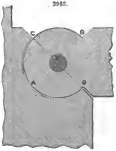
3966.



3967.



3968.



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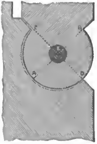

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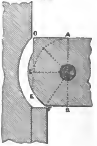


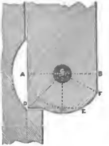
Figs. 3968, 3969; Figs. 3970, 3971; Figs. 3972, 3973; and Figs. 3974, 3975, are examples of centre-pin joints, and require no particular or detailed describing.

Figs. 3976 to 3978 are of a hinge, the flap of which has a bead B closing into a corresponding hollow, so that the joint cannot be seen through.

Figs. 3979 to 3981 show a hinge *b a* let equally into the styles, the knuckles of which form a part of the bead on the edge of the style B. In this case the beads on each side are equal and opposite to each other, with the joint-pin in the centre.

In the example, Figs. 3982 to 3984, the knuckle of the hinge forms a portion of the bead on the

3971.



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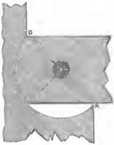

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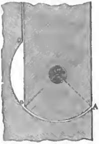

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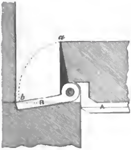

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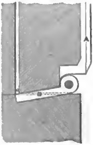

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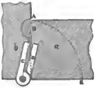

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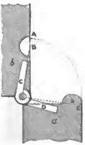

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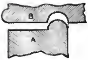

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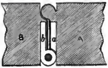

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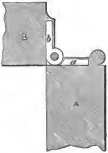

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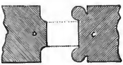

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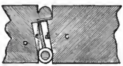

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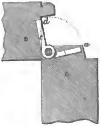
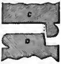


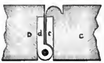
3984.



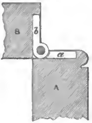
style C, and is equal and opposite to the bead of the style D. In Figs. 3985 to 3987, the beads are not directly opposite to one another.

Fig. 3988 exhibits the hinging of a back flap when the centre of the hinge is in the middle of the joint.

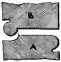
3985.



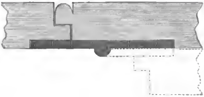
3986.



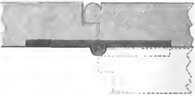
3987.



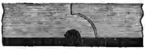
3988.



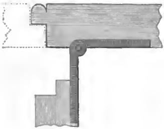
3989.



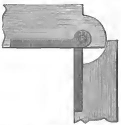
3991.



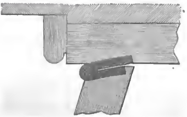
3990.



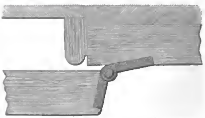
3992.



3993.



3994.

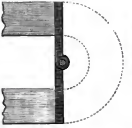


Figs. 3989, 3990, relate to the manner of hinging a back flap when it is necessary to throw the flap back from the joint. An example of a rule-joint is given, Figs. 3991, 3992.

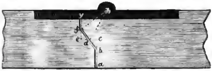
Figs. 3993, 3994, point out or define the ordinary mode of hinging shutters to sash-frames.

Figs. 3995, 3996, Illustrate a method of hinging employed when the flap on being opened has to be at a distance from the style. This method of hinging is used on the doors of pews, to throw the opening flap or door clear of the mouldings.

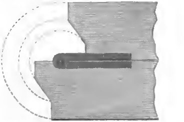
3995.



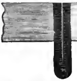
3997.



3998.



3996.



Figs. 3997, 3998, show the manner of finding the rebate when the hinge is placed on the contrary side. Let *h* be the centre of the hinge, *y e* the line of joint on the same side, *a c* the line of joint on the opposite side, and *e c* the total depth of the rebate. Bisect *e c* in *d*, and join *d h*; on *d h* describe a semicircle cutting *y e* in *f*, and through *f* and *d* draw *f b*, cutting *a c* in *b*, and join *a b*, *b f*, and *f y*, to complete the joint.

HOE. Fr., *Houe*; Ger., *Hacke*; Ital., *Zappa*; Span., *Azadon*.

No peculiar mechanical skill is employed to form a *hoe*, which is an instrument for cutting up weeds and loosening the earth; it is composed of a plate of iron, with a handle, which is set at an acute angle with the plate. See Hand-Tools, p. 1834.

HOIST. Fr., *Élévateur*; Ger., *Aufzug*; Ital., *Verricello, monta sacchi*; Span., *Aparejo para elevar*.

See Lifts; Hoists; and Elevators.

HOP-ELEVATOR. Fr., *Élévateur à houblon*; Ger., *Elevator für Hopfen*; Ital., *Montaluppolo*; Span., *Elevador de lúpulo*.

See Lifts; Hoists; and Elevators.

HORSE-POWER, or Horse-Engine.

A *horse-power*, or, more properly speaking, a horse-engine, operated by one horse or more, is a machine generally employed to convert a slow motion into a rapid one; it effects the lighter operations of grinding, polishing, or pulverizing. There are many kinds of those easily-formed contrivances; the well-known *horse-power*, invented by that ingenious mechanic, the late James Bogardus, of New York, is very complete. See Agricultural Implements, p. 12. Arrastre, p. 142.

HORSE-POWER (HP.) *and other Units of Work.* Fr., *Cheval de force, et d'autre unités des travails mechaniques*; Ger., *Pferdekraft und andere Krafteinheiten*.

A horse-power is a unit or standard of work by which the capabilities of steam-engines and other prime-movers are measured; in England a horse-power is estimated 33,000 lbs. raised 1 ft. in a minute. 33,000 units of work a minute is = 550 units of work a second. One HP., or one *Force de Cheval* French measure, is equal to 75 kilogrammes raised a mètre in the direction of the plumb-line in a minute. 366 *Force de Cheval* is very nearly equal to 361 HP. British. See Algebraic Signs, p. 43. Belts. Boiler, p. 425. Brake, p. 597. Details of Engines. Dynamometer Car. Gunnery, p. 1744. Indicators. Principle of Work.

HOT-BLAST STOVES. Fr., *Appareil à air chaud*; Ger., *Winderhitzungsapparat*; Ital., *Calorifero*; Span., *Calorífero termodinámico*.

See Stoves.

HOWITZER. Fr., *Obusier*; Ger., *Haubitze*; Ital., *Obice*; Span., *Obus*.

A short, light, peculiarly-formed cannon is termed a *howitzer*; it has a chamber, and is intended to throw large projectiles with comparatively small charges; it is so short that the projectile, when hollow, can be put in its place by hand. See Ordnance.

HUB. Fr., *Moyeu*; Ger., *Nabe*; Ital., *Mozzo*; Span., *Cubo*, or *pina*.

A *hub* is a projection on a wheel for the insertion of a pin; as a crank-pin *hub*. This term is often written *hob*. See Wheels.

HYDRANT. Fr., *Tuyau d'alimentation hydraulique*; Ger., *Hydrant*; Ital., *Ramo di tubo*; Span., *Boca de agua*.

See Hydraulic Machines, *Varieties of*.

HYDRAULICS. Fr., *Science hydraulique;* Ger., *Wassermaschinenkunde;* Ital., *Idraulica;* Span., *Hidráulica.*

Hydraulics is that department of engineering which treats of fluids in motion, especially of water, which in motion presents itself in four different ways; as passing out of a reservoir; flowing in a bed; acting as a motor; and in a passive state raised by machines.

There are two quantities to be found in all calculations relating to this science—the weight of water and the intensity of gravity. These quantities are variable, but almost always supposed constant. What follows will enable us to judge of the error which may result from this supposition.

When water is entirely pure, and is taken at its *maximum* density, it weighs 62·4491 lbs. a cubic foot: such is its *specific weight.* It may vary from three causes. The most powerful is the temperature. We know that heat expands bodies, and this diminishes their density or specific weight. From accurate experiments, the density of pure water, at different degrees of Centigrade and Fahrenheit thermometers, would be as indicated in the following Table;—

Temperature.		Weight of a cubic mètre.	Weight of a cubic foot in lbs.	Temperature.		Weight of a cubic mètre.	Weight of a cubic foot in lbs.
Centigrade.	Fahrenheit.			Centigrade.	Fahrenheit.		
		kil.				kil.	
4	$39\frac{1}{5}$	1000·	62·449	20	68	998·24	62·339
6	$42\frac{4}{5}$	999·95	62·446	25	77	997·99	62·268
8	$46\frac{2}{5}$	999.87	62·441	30	86	995·73	62·182
10	50	999·72	61·432	50	122	987·58	61·673
12	$53\frac{3}{5}$	999·54	62·420	100	212	956·70	59·745
15	59	999·14	62·396				

Below 4° Centigrade or 39° Fahrenheit, the density, instead of continuing to increase, diminishes; this diminution, at first very slow, rapidly progresses towards the limit of congelation, and the weight of a cubic foot of ice is only 58·078 lbs.

The effects of pressure are much less sensible. Water was, for a long time, considered wholly incompressible; but experiments have shown that, under very heavy loads, it is really compressed, although but a very small quantity; about 0·000046 of its volume under the weight of one atmosphere; that is, under a pressure represented by the height of a column of mercury in a barometer, a height estimated at 29·922 in., and which is equivalent to the height of a column of water about 33·793 ft. But as, in common practice, we shall not have to calculate upon such depths or heights of water, we may, without sensible error, entirely neglect the effects of pressure.

What proceeds from saline or earthy substances contained in the waters which run on the surface of the globe, may also, in most cases, be omitted, the specific weight of the water of rivers being only one or two ten-thousandths greater than that of distilled water, which is taken as the standard of perfectly pure water. Professor Boisgarand found, by many trials, made with great care, $1000^{k}\cdot149$ for the specific gravity of the water of the Garonne, that of distilled water being 1000 kilogrammes to the mètre, or 62·449 lbs. to the cubic foot. Brisson has nearly an equal result for the Seine. Moreover, a mass of water, when surrounded by air, loses, like all other bodies, a part of its weight equal to the weight of air whose place it occupies; and this loss, which is seldom below $\frac{10}{100000} = \cdot00010$, may be even $\frac{13}{100000} = \cdot00013$.

Finally, in our mean temperatures, and according to different circumstances, the weight of a cubic foot of water will be only from 62·35 lbs. to 62·39, or the cubic mètre from $998^{k}\cdot4$ to 999^{k}. We shall, however, constantly admit 1000^{k}, this value rendering the conversion of cubic mètres of water into kilogrammes, and *vice versâ*, extremely easy.

Experiments made at the observatory of Paris, gave $0^{m}\cdot9934 = 39\cdot128$ in., or 3·2606 ft., for the length of a pendulum vibrating seconds, this length being reduced to the level of the sea. Whence we conclude that, in that place, a heavy body descends $4^{m}\cdot9044 (= \frac{1}{2} \times 0\cdot99384\pi^2) = 16\cdot091$ ft., during the first second of its fall. If, at the end of that time, gravity ceased to act upon it, it would continue to descend, but with a uniform motion, running through double the space, or 32·182 ft. a second; this number, which expresses the velocity impressed by gravity in the unit of time, represents, for Paris, the intensity of that accelerating force; we generally designate that intensity or velocity by g, the initial letter of the word *gravity.* (See our article Gunnery.) g augments with the latitude, and diminishes with the elevation above the level of the sea, and generally we have the empirical formulas;—

$$\begin{array}{ll} \text{In feet} & \left\{ g = 32^{ft}\cdot16954\,(1 - 0\cdot00284 \cos. 2\,l)\left(1 - \frac{2\,e}{r}\right), \right. \\ \text{In mètres} & \left\{ g = 9^{m}\cdot8051\,(1 - 0\cdot00284 \cos. 2\,l)\left(1 - \frac{2\,e}{r}\right), \right. \end{array}$$

l being the latitude of the place, e its elevation above the level of the sea, r the radius of the terrestrial spheroid at the level of the sea in that place;—

$$\{ r = 6366407^{m}\,(1 + 0\cdot00164 \cos. 2\,l) \} = 20887510 \text{ ft. } (1 + 0\cdot00164 \cos. 2\,l).$$

Thus, at Toulouse, where $l = 43°\ 36'$ and $e = 146^{m} = 479$ ft., we have $g = 9^{m}\cdot8032 = 32\cdot1633$ ft.; at Montlouis, where $l = 42°\ 30'$ and $e = 1620^{m} = 5315$ ft. (the mean height of the barometer being 29·72 in.) (Journal des Mines, tom. 23, p. 318), $g = 9^{m}\cdot7977 = 32\cdot1453$ ft.

Notwithstanding these variations, for the want of knowing better, we take $g = 9^{m} \cdot 8808 = 32 \cdot 1817$. However, according to the examples we have just seen, the results of calculations into which this quantity shall enter, may be in error, even for France, more than one-thousandth.

The value of g will very often appear under two forms, of which we give the origin.

According to the first principle of the fall of heavy bodies, and of uniformly accelerated motion in general, the velocities acquired are as the times occupied in acquiring them; so that if v is the velocity acquired by a body at the end of the time t, g being, as we have just seen, the velocity acquired in 1″, we shall have $v : g :: t : 1$, or $v = g\,t$.

According to the second principle, the spaces passed through, or the heights of the falls, are as the squares of the times occupied in passing through them; then if h is the height through which the same body has fallen in the time t, $\frac{1}{2}\,g$ being the fall corresponding to 1″, we shall have

$$h : \tfrac{1}{2}\,g :: t^2 : (1'')^2, \text{ or } h = \frac{g\,t^2}{2}.$$

Taking the value of t in this latter equation, and substituting it in the first, we have

$$v = \sqrt{2\,g\,h}, \text{ and consequently } h = \frac{v^2}{2\,g}.$$

Since $g = 9^{m} \cdot 8088 = 32 \cdot 182 \text{ft.}$, $\sqrt{2\,g} = \sqrt{64 \cdot 361} = 8 \cdot 0227$, and $\frac{1}{2\,g} = \cdot 015536$.

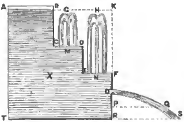
Consequently, $v = 8 \cdot 0227 \sqrt{h}$; and $h = \cdot 015536\,v^2$.

We call v *the velocity due to the height* h, *and* h *the height due to the velocity* v.

The Greek letter π, which we have employed in other places, as it expresses the ratio of the circumference to the diameter (3·1416), it has no other acceptation in this article. The fourth of that quantity (·7854), which is the ratio of the circle to the circumscribed square, presenting itself very frequently in calculations, we shall designate by π'.

General Principles.—Let X, Fig. 3999, be a vessel kept constantly full of water up to A B. If on the horizontal faces C D and E F are made the orifices M and N, the fluid will pass out in the form of vertical jets, which will rise nearly to the level A K of the water in the reservoir; they would quite attain that level, if certain causes, to be investigated in the sequel, opposed no obstacle.

3999.



Now, from the first principles of dynamics, in order that a body thrown vertically may attain a certain height, it is necessary that at its point of departure it receive a velocity equal to that which it would have acquired by falling freely from the same height. Consequently, since the fluid particles which pass from the orifices M and N are raised to the respective heights M G and N H on passing out, they must have been impelled with velocities due to those heights, which are the heights of the surface of the reservoir above the orifices. In like manner, if on a vertical face F R an opening O be made, we shall hereafter see that, according to the respective values of the lines O P and P Q, the fluid passes out at O with a velocity due to the height O K. It would pass out with a velocity due to K R, if the orifice were opened on the bottom R T of the vessel.

It will always be thus with these different orifices, whatever be their magnitude compared to the transverse section of the vessel, provided, however, that the fluid surface, preserving a constant level, remain even and *tranquil*; a condition which could not be fulfilled, if the size were very large, the water flowing out producing violent commotion in the vessel.

Generally, and making abstraction of every obstacle or all cause of perturbation, *the velocity of a fluid, at its passage through an orifice made in the side of a reservoir, is the same as a heavy body would acquire in falling freely from the height comprised between the level of the fluid surface in the reservoir and the centre of that orifice.*

This theorem, known under the name of Torricelli's theorem, was established and published by that celebrated philosopher in 1643, as a consequence of the laws of the fall of heavy bodies.

If we designate by v the velocity of issue, and by H the height or head of water in the reservoir, it will give $v = \sqrt{2\,g\,\text{H}}$.

We have just seen that water passing from the openings M and N did not quite attain the level of the fluid in the reservoir. If to these openings we adapted two perfectly equal tubes, the water would rise still less high; but the diminution of height would follow exactly the same ratio. For example; if the jet which issues from the tube at M were only two-thirds of M G, that which would pass from the tube at N would be only two-thirds of N H. In general, let n be the ratio between the height of the jet and that of the reservoir for a tube of a certain form, H and H′ two heights of the reservoir, and v and v' the corresponding velocities, we shall have

$$v = \sqrt{2\,g\,n\,\text{H}} \text{ and } v' = \sqrt{2\,g\,n\,\text{H}'}; \text{ whence } v : v' :: \sqrt{\text{H}} : \sqrt{\text{H}'};$$

that is to say, the openings being of the same form, *the velocities are always as the square roots of the heads.*

Experiments made by Mariotte, and repeated a hundred times since, leave no doubt as to this principle. We will here give the results of some of them; this will fix the degree of confidence with which the principle may be received; other details from the series of experiments which furnished these will be given presently. The first series was made by M. Castel and D'Aubuisson; the second, by Bossut; the third and fourth, by Michelotti; and the last, by MM. Poncelet and Lesbros.

It will be remarked that the heads were varied in the ratio of 1 to 200 and more, and the sections of the orifices from 1 to 500; and yet, in all, the velocities followed the ratio of the square roots of the heads; the small differences which are seen, sometimes in excess, sometimes deficient, may be neglected;—small errors are inevitable in such experiments. Their direct object was the determination of the discharges; but it is evident that when the orifice is the same, the discharge varies only with the velocity, that it is exactly proportional to it, and that the series of ratios of one is also the series of ratios of the other.

The general principle that the velocities are as the square roots of the heads, as well as the theorem of Torricelli for cases where it is applicable, extends to fluids of all kinds; to mercury, oil, and even aëriform fluids. So that the velocity with which each of them passes an orifice, is independent of its nature and of its density: it depends only on the head; experience proves it.

Simple reasoning, also, can show that it must be so. Take mercury, for example; the particles placed before the orifice, and on which it is necessary to impress a certain velocity, are, it is true, fourteen times more dense than those of water, and therefore they oppose fourteen times as much resistance to motion; but as the mass which presses, and which produces the velocity of passing out (being about fourteen times greater), exerts a motive effort fourteen times greater, there is a compensation, and the impressed velocity remains the same.

Diameter of Orifice.	Head of Orifice.	Series of	
		Square roots of Heads.	Discharges or Velocities.
inches.	inches.		
0·3937	1·024	1·000	1·000
	1·181	1·074	1·064
	1·575	1·241	1·244
	1·969	1·386	1·393
	2·362	1·519	1·524
	feet.		
1·063	4·265	1·000	1·000
	9·580	1·500	1·497
	12·500	1·713	1·707
3·189	7·677	1·000	1·000
	12·500	1·305	1·301
	22·179	1·738	1·692
6·378	6·923	1·000	1·000
	12·008	1·316	1·315
squares.	1·312	1·000	1·000
—	2·297	1·323	1·330
7⅞ in.	2·281	1·581	1·590
by	4·265	1·803	1·806
7⅞ in.	5·249	2·000	2·000

To the pressure which a fluid contained in a vessel exerts by its weight on the orifice of exit, may be added a foreign pressure, and the velocity of flowing is augmented. What will be its increase and its definite value?

Let P be the weight of body which produces the pressure, and s the fluid surface or portion of the fluid surface on which it immediately acts, namely, that which is in contact with it; h the elevation of that surface above the orifice, and p the weight of a cubic foot of the fluid contained in the vessel. For the given body substitute, in imagination, a column of that fluid, which would have s for its base, and whose height h' would be such that the weight of the column would be equal to that of the body; we should thus have $P = p\,s\,h'$ from which to deduce h'; substituting thus one body for another of equal weight, we should not change the pressure experienced by the particles contained in the vessel. Suppose, further, that after having withdrawn the body, we add in the vessel (whose sides we may suppose to be prolonged to an indefinite height) a quantity of the same fluid as that already contained, until its level has attained the summit of the column; according to the laws of hydrostatics, all the mass of the fluid added would only produce a pressure equivalent to that of a single column; so that the particles situated before the orifice would experience a pressure exactly equal to what they first experienced, and will always tend to pass out with the same velocity. Now, in the new state of things, the height of the reservoir above the orifice, the height generating the velocity of exit, is evidently $h' + h$, and consequently this velocity will be $\sqrt{2\,g\,(h' + h)}$.

Take, for example, a vessel closed on all sides and filled with alcohol, whose specific gravity is 0·837; on the cover is a circular opening of 1¼ in. diameter, in which is a piston loaded with 18 oz.; the orifice of exit is 10 in. beneath that opening. To determine the velocity with which the alcohol will run out. We admit that the friction of the piston on the edges of the opening is balanced by the weight of the piston itself.

We then have $P = 18$ oz. $= 1·125$ lb.; $s = ·7854 \times (1·25)^2 = 1·227$ sq. in. $= ·0085$ sq. ft.: $p = ·837 \times 62·429 = 52·271$ lbs. and $h = 10$ in. $= ·833$ ft.; for h', the equation $P = p\,s\,h'$ or $1·125 = 52·271 \times ·0085\,h'$, gives 2·5329 ft. Thus the alcohol will issue with a velocity of

$$\sqrt{2\,g\,(2·5329 + ·833)} = \sqrt{64·364 \times 3·3659} = 14·718 \text{ ft.}$$

If the vessel were not kept constantly full, this velocity would gradually diminish.

After having given the expression of the velocity with which any fluid issues from an orifice, we pass to the use made of it in determining the discharge.

We call the *discharge* of an orifice the volume of fluid which runs out of it in the unit of time, the second.

If the mean velocity of all the fluid particles were that due to the whole head H, this velocity, which is then called *theoretic velocity*, would be $\sqrt{2\,g\,H}$; if, at the same time, the particles passed

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out from all points of the orifice, and in parallel lines, it is evident that the volume of water running out in one second would be equal to the volume of a prism which had the orifice for a base, and that velocity for its height; it would be, calling S the area or section of the orifice, $S\sqrt{2gH}$. This is the *theoretic discharge.*

But the *actual discharge* is always less.

To give an accurate idea of the state of things, let us consider the fluid vein a little after its passage from the orifice, and let us cut it by a plane perpendicular to its direction. It is manifest that the discharge will be equivalent to the product of the section by the mean velocity of the lines, at the instant of their crossing the section: If this section were equal to that of the orifice, and if this velocity be equal to that due to the head, the actual discharge would be equal to the theoretic discharge. But it happens, either that the section of the vein is sensibly smaller than that of the orifice, as in flowing through orifices in a thin side, or that the velocity at the section is sensibly less than that due to the head, as in cylindrical tubes; or even that there is a diminution both in the section and in the velocity, as in certain conical tubes. So that the actual discharge will, in all these different cases, be less than the theoretic; and in order to reduce the theoretic to the actual, it must be multiplied by a fraction. If m represent that fraction, and Q the actual discharge, we shall have $Q = mS\sqrt{2gH}$.

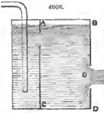
Designating by Q′ the volume of water flowing in any time T, we should also have

$$Q' = mST\sqrt{2gH}.$$

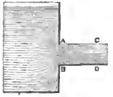
Whether the diminution in the discharge proceed from a diminution in the section of the vein, or from a diminution in the velocity, it is always a consequence of the contraction which the vein experiences on passing through the orifice: thus the multiplier *m, or coefficient of reduction of the theoretic discharge to the actual discharge,* is commonly called *the coefficient of the contraction of the fluid vein,* or simply, *coefficient of contraction.* Its determination is one of very great importance; on its accuracy depends that of the results obtained when the formula for the flow of fluids is applied to practice; it has also been the great object of the experimental researches of hydraulicians. We will make known the results to which they have arrived, after making some preliminary observations.

On Contraction and its Effects.—Take a transparent vessel, Figs. 4000, 4001, let water flow through an orifice in its side, and make the motion of the particles of the fluid visible by mixing with them small substances of a specific gravity about equal to that of the water, such as saw-dust of certain kinds of wood; or, better still, by introducing light chemical precipitates, such, for example, as take place when drops of the solution of nitrate of silver are poured into water slightly salted; at a small distance from the orifice, say from 1 in. to 1½ in. for an orifice of ¾ in. diameter, the fluid particles directed from all parts towards the orifice are seen to describe curved lines, and to terminate by passing towards the orifice with a very accelerated motion, as towards a centre of attraction.

4000.



4001.



The convergence of the directions which they take in the interior of the vessel, on the instant of their arrival at the orifice, still continues for a little distance after they have passed through it, so that the fluid vein, at its passage from the orifice, is gradually contracted up to a point where its particles, by the effect of their reciprocal action, and of the motions impressed upon them, take a parallel direction, or other directions. The vein thus forms a kind of truncated pyramid or cone, whose greater base is the orifice, and whose smaller is the fluid section at the point of greatest contraction—a section which is often called *the section of the contracted vein.* This figure, and all the phenomena of contraction, are thus a consequence of the convergence of the lines, when they arrive at the orifice, or of the obliquity of the direction of some in respect to others.

When the orifice is in a thin side, the contraction takes place below the plane of that orifice; it is *exterior;* it is seen; its dimensions can be measured, and they have actually been measured. We shall soon tell what has been done in this respect; we shall here simply remark that in circular orifices beyond the section of the greatest contraction and up to a certain distance, the vein continues in the form of a cylinder, of which that section would be the base, and with a velocity nearly that due to the height of the reservoir. The discharge, then, will be the product of that section by that velocity; so that the contraction will be limited to reducing the section which is to enter into the expression of the discharge. The flowing takes place as if, for the real orifice, another had been substituted, of a diameter equal to that of the contracted section, and as if there had been no contraction.

If to the orifice A B, a cylindrical tube A B C D be fitted, the fluid lines will arrive at A B converging, and consequently the fluid will be contracted at the entrance of the tube. Experiments, to be given hereafter, will indicate that the contraction there is equal to that which takes place in orifices with thin sides; it would be only *interior* in relation to the mouth of the outlet. Moreover, beyond the contracted section, the attraction of the sides of the tube occasions a dilation of the vein; the threads are carried against the sides, they follow the sides, and pass out parallel to each other, and to the axis of the tube; so that the section of the vein at its exit is quite equal to that of the orifice, but the velocity is not that due to the head of the reservoir. If the flowing were produced only by the simple pressure of the fluid contained in the reservoir, probably the velocity, at the section of greatest contraction, would be that due to the head, then it would diminish in proportion as the vein dilates, in virtue of the law or axiom of hydraulics, *when an incompressible fluid in motion forms a continuous mass, the velocity, at its different sections, is in the inverse ratio of the area of the section*; the diminution would cease when, the vein having attained the sides, its section would become equal to that of the orifice. Since m is the ratio of the section of greatest contraction to that of the orifice, the velocity along the sides, and consequently at the exit, would be $m\sqrt{2gH}$; and for the discharge we should have $S \times m\sqrt{2gH}$.

In orifices in a thin side, it was $mS \times \sqrt{2gH}$: thus the discharge would be the same in both cases; the only difference is, that in the latter the diminution would have affected the factor S, and in the tubes it would have fallen on the factor $\sqrt{2gH}$; that is to say, on the velocity. But the attractive action of the sides changes this state of things; not only does it cause the lines to deviate from their direction, but it also increases their velocity, so that the velocity of exit is greater than $m\sqrt{2gH}$; it will be $m'\sqrt{2gH}$, m' being a fraction greater than m; and the discharge will become $S \times m'\sqrt{2gH}$.

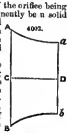
We see by this, that in cylindrical tubes and in ajutages generally, the effect of contraction is involved in that of the attraction of the sides. Without being able to assign what belongs to the first alone, we will remark that for every interior contraction there is a corresponding diminution of velocity, and every exterior contraction produces a diminution of section.

Let us examine the form which contraction gives to the fluid vein passing from an orifice. Take first the most simple case, that of a circular orifice in a thin and plane side.

The direction as well as the velocity of the particles at the different points of the orifice being symmetrical, the contracted vein must also have a symmetrical form, and consequently be a solid of revolution, a conoid. It is so in fact, and observations about to be reported give it the form represented by A B b a, Fig. 4002. Beyond a b the contraction ceases, and the vein continues under a form sensibly cylindrical for a certain length, and until it becomes entirely deformed, from the resistance of the air and other causes.

In the first part of that length it is full, clear, sometimes like a bar of the most beautiful crystal; then it becomes disturbed, and, examined in a strong light, it presents a series of swellings and contractions. From the very ingenious experiments of M. Savart, the appearance of continuity of the disturbed part is only an optical illusion, arising from the rapidity of the motions; this part consists of a series of distinct drops, alternately large and small, leaving between each other a space eight or ten times greater than their mean diameter, the form of which, oscillating round that of a sphere, is alternately an elongated and an oblate spheroid.

4002.



Boyle observed that the length of the clear part, as well as that of the swellings in the disturbed part, increased proportionally to the diameter of the orifice and the head; for the clear part, it was nearly $380\,d\sqrt{h}$ in mètres, or $209\,d\sqrt{h}$ in feet. The formation of drops, that is to say, their detachment from the clear part, is not, even in descending jets, an effect of the acceleration of velocity due to gravity; for it takes place equally in jets thrown upwards. It appeared to Savart to be an immediate effect of the oscillation which occurred in the fluid of the reservoir, in consequence of which the particles of the jet, being sometimes more and sometimes less pressed at their exit from the orifice, moved with a velocity alternately greater and less. D'Aubuisson discovered such alternations in most of the motions of fluids. He observed them also, in a very marked manner, during his experiments upon the resistance which the air experiences in conduit pipes.

M. Savart also showed the very singular influence of the waves of sound on the liquid veins; for example, if the disturbed part be received on the bottom of a vessel, there is heard a sound due to the impulse of successive drops; if then a note be produced on a violin in unison with this sound, the clear part of the jet is immediately seen to become shortened, and sometimes even to disappear entirely; the swellings of the troubled part become bigger and shorter, and the space which separates them is greater.

To return to the commencement of the jet, to the contracted vein properly so called, the conoid A B b a, Fig. 4002. Attempts have been made to determine its respective dimensions, and particularly the ratio between the diameters of the two bases, by direct measurements. Newton, who observed the phenomenon of contraction and its effects on the discharge, and first attempted such an admeasurement; he concluded that the ratio of the section of the orifice to the contracted section was that of $\sqrt{2}$ to I, and consequently that of the diameter was as I to 0·841; but we believe that theoretical considerations, rather than a physical measurement, led him to adopt that result. Since then, several philosophers have made like measurements; thus A B being 1; Poleni found for $a\,b$ 0·79; Borda, 0·804; Michelotti, 0·792; Bossut, from ·812 to ·817; Eytelwein, ·80; Venturi, ·798; finally, Brunaci, ·78. Nearly all these numbers, whose mean term is ·80, are very probably a little too large; they were found by measurements taken with callipers; if closed too much, the points were thrust into the body of the stream and the disturbance indicated it; but if too much open, the eye could not exactly appreciate how much it was so; hence an error in excess might be made, but not one in deficiency.

Michelotti the younger took up this question, which had already been treated by his father. Large jets obtained under great heads, gave him the following results.

Head above the Orifice in feet.	Diameter in inches.		Ratio between Diameters.	Distance from Orifice to Contraction, in inches.	Ratio of the Distance to the Contracted Diameter.
	At the Orifice.	At the Contraction.			
6·890	6·394	5·047	0·790	2·520	0·501
12·008	6·394	5·039	0·788	2·520	0·500
7·349	3·197	2·511	0·786	1·260	0·500
12·502	3·197	2·504	0·783	1·210	0·492
22·179	3·197	2·413	0·755	1·181	0·497

Abstracting the last number 0·755, which is entirely anomalous, the mean ratio between the two diameters is 0·787. From what has been said, we think it may be adopted, but only as a mean term; for, as we shall soon see, this ratio experiences variations, slight, to be sure, which depend upon the heads and the diameters of the orifices. The length of the contracted vein should be about half the diameter of the smallest section, or 0·39 of the diameter of the orifice. According to these experiments, the three principal dimensions, A B, *a b*, and C D, Fig. 4002, of the contracted vein would be respectively as the numbers 100, 79, and 39.

Eyteiwein, chiefly increasing the last dimension, one very difficult to determine with accuracy, takes the numbers 10, 8, and 5; this ratio is quite generally admitted. As to the curves A *a* and B *b*, Michelotti refers them to a cycloid. In conclusion, the form of the fluid vein, at its passage from a circular orifice, has some resemblance to the bell-shaped end of a hunting horn.

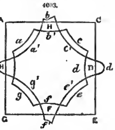
The ratio between the diameters being 0·787, that between the sections will be the square of 0·787, or 0·619; thus, if s is the section of the contracted vein and S that of the orifice, we shall have $s = 0·619\ \mathrm{S}$. From the explanations made, p. 1889, the discharge will be $s\sqrt{2 g \mathrm{H}}$ or $0·619\,\mathrm{S}\sqrt{2 g \mathrm{H}}$. So that m, or the coefficient of contraction given by physical measurements of the vein, will be at a mean 0·619; and the measurements of the discharge indicate nearly the same.

If the velocity due to the head of the reservoir were really the *velocity at the passage* of the contracted section, and the flowing were produced through a tube which had exactly the form of the contracted vein, by introducing into the expression of the discharge the exterior orifice of that tube or s, the calculated discharge would be equal to the real discharge, and the coefficient for reducing one to the other would be 1. Michelotti, in one of his experiments, by employing a cycloidal tube, found it 0·984; it is probable that it would have come up to 1, if the sides of the tube had been more exactly bent to the curvature of the fluid vein; and if the resistance of the sides, as well as that of the air, had not slightly retarded the motion.

Orifices, whose perimeter is a polygon, or any figure other than a circle, do not present a form so simple, or leading to the same consequences.

The different parts of the orifices not being symmetrical, the fluid vein does not preserve the form which it had on coming out, and it changes from it continually as it removes from it. At its exit, the faces corresponding to the rectilinear sides of the orifice become more and more concave; the edges corresponding to the angles become truncated and terminate by disappearing. Thus Poncelet and Lesbros, having drawn, by aid of very exact means, the form of a vein which passed from a square orifice A C E G, Fig. 4003, whose sides were 7¾ in. under a head of 5½ ft., had, at the distance of 5·9 in. from the orifice, the section *a c e g*; and at 11·81 in., the section *b′ d′ f′ h′*.

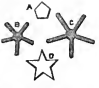
4003.



This last, one of the nine sections observed, was the smallest; its area was to that of the orifice in the ratio of 0·562 to 1, whilst that of the actual discharge to the theoretic discharge was found to be 0·605; they would have been equal, if the velocity of that smallest section had been due to the head of the reservoir.

Although the fluid particles at *b′ c′ d′*, &c., on this section, Fig. 4003, are those which came out at the points B C D, &c., of the orifice, and in removing from the reservoir have always remained on the line of intersection of the vein with the planes passing through its axis and those points respectively, it is nevertheless true that the section *b′ d′ f′ h′* is a kind of square, the vertex of whose angles corresponds to the middle of the sides of the square of the orifice; and that the vein appears to have made an eighth of a revolution round its axis. A phenomenon of this nature is produced on all the veins which come out of an orifice not circular; it is called the *reversing of the vein*.

4004.



The orifice was a regular pentagon A, Fig. 4004, of 0·551 in. each side, made in a thin vertical plate of copper (the figure representing it, with its accessories, is one-quarter of the natural size); the flowing took place under a head of 6·463 ft. At the distance of 0·472 in., the section perpendicular to the axis of the vein was a quite regular decagon. At 1·181 in. was the greatest contraction or *first knot*. Beyond, the vein entirely changed its form; it presented five fluid plates, disposed symmetrically around the axis, as is seen in the section B, made 3·74 in. from the orifice; the planes of the blades passed through the centres of the sides of the orifice. Their breadth continued to increase up to the belly of the vein represented at C. Then it diminished, and the blades united anew in a *second knot*, at 2 ft. 10 in. from the orifice. Beyond, the vein was twisted and irregular.

For the rectilinear pentagon of the orifice were successively substituted pentagons with convex and concave sides, sides presenting salient and re-entering angles like the star D, and the vein always preserves the same form, the same five blades.

With orifices of six and eight sides, we had six and eight blades; and the reversing of the vein was a twelfth and sixteenth of the circumference. When the opening was a rectangle, narrow, and very long in the horizontal direction, at a certain distance, the vein consisted only of a broad vertical blade; the reversing seemed complete.

Often, beyond the second knot, the vein dilates again and divides a second time into the same number of blades; but their plane does not correspond to the middle of the sides of the orifice, but to the vertex of the angles; that is to say, the vein is again turned an equal quantity, or rather it returns to its place. The blades increase in breadth up to the second belly, and diminish again to form a third knot, beyond which sometimes there is still a new dilation, a third belly and a fourth knot.

Orifices in Thin Partitions.—We now come to the direct determination of the coefficient of reduction, from the theoretic to the actual discharge.

And we will measure with care the volume of water passing from a given orifice, under a constant head, and during a certain time; and we shall derive from it the product of the flow in one second or the actual discharge; we will divide it by the theoretic discharge corresponding to that orifice and to that head, and the quotient will be the coefficient sought.

Many hydraulic engineers have applied themselves to this investigation; D'Aubuisson gives, in the following Table, the principal results obtained up to the present time; those which appear to have been made under the most favourable circumstances, or which were generally admitted.

Circular Orifices.			
Observers.	Diameter in inches.	Head in feet.	Coefficient.
Mariotti ..	0·268	5·873	0·692
" ..	0·268	25·920	0·692
Castel	0·394	2·133	0·673
"	0·394	1·017	0·654
"	0·590	0·453	0·632
"	0·590	0·984	0·617
Eytelwein ..	1·027	2·372	0·618
Bossut	1·067	4·265	0·619
Michelotti ..	1·067	7·317	0·618
Castel	1·181	0·223	0·629
Venturi	1·614	2·887	0·622
Bossut	2·126	12·500	0·618
Michelotti ..	2·126	7·218	0·607
" ..	3·189	7·349	0·613
" ..	3·189	12·500	0·612
" ..	3·189	22·179	0·597 ?
" ..	6·378	6·923	0·619
" ..	6·378	12·008	0·619

Square Orifices.			
Observers.	Side of square in inches.	Head in feet.	Coefficient.
Castel	0·394	0·164	0·655
Bossut	1·063	12·500	0·616
Michelotti ..	1·063	12·500	0·607
" ..	1·063	22·409	0·606
Bossut	2·126	12·500	0·618
Michelotti ..	2·126	7·349	0·603
" ..	2·126	12·566	0·603
" ..	2·126	22·245	0·602
" ..	3·228	7·415	0·616
" ..	3·189	12·566	0·619
" ..	3·189	22·376	0·616

Rectangular Orifices (Bidone).			
Rectangle.		Head in inches.	Coefficient.
Height in inches.	Base in inches.		
0·362	0·728	13	0·620
0·362	1·457	13	0·620
0·362	2·909	13	0·621
0·362	5·818	13	0·626

The most remarkable of all these experiments, as well for the great size of the jets as for the greatness of the head, are those which Michelotti executed in 1764, at the fine hydraulic establishment constructed for that purpose at about two miles from Turin; the reservoir consisted of a tower 26 ft. 3 in. high, whose interior, which is a square of 3·182 ft. a side, receives through a canal the waters of the Doire. On one of the faces were fitted, at the different heights, the orifices or tubes which were thought proper; arrangements were made to receive them, and on the ground, which is at the base, were several measuring basins. These experiments were repeated in 1784 by Michelotti the younger, and they are the last introduced into the Table.

The experiments just reported and those made by other authors have shewn that the coefficient of contraction is generally greater for small orifices and small heads; but they furnished only vague and almost contradictory notions in this respect. It would have been impossible to deduce from them the series of coefficients from great orifices to the smallest, and from great heads to the smallest; this deficiency has recently been supplied by MM. Poncelet and Lesbros. They made, in 1826 and 1827, at Metz, a series of experiments on a *very* great scale, and with care and means which had not before been employed.

They appear to have nearly solved the great and useful problem of the contraction of the vein in a thin partition, perhaps as nearly as the nature of the subject admits; and in a manner, if not entirely theoretical, at least very suitable to applications.

In these experiments the orifices were rectangular, and all of $0^{\text{m}}\cdot 2$ = 7·874 in. base; the heights were successively 7·874 in., 3·937 in., 1·968 in., 1·18 in., 0·787 in., 0·394 in.; the heads varied from 0·394 in. to 5·577 ft. For each of these orifices the discharge was measured with several repetitions, under seven or ten heads, of which the two extremes were taken, the one nearly as small and the other as large as the apparatus allowed; and the corresponding coefficients were calculated.

Taking, then, the heads for abscissas and their coefficients for ordinates, the curve relating to that orifice was traced; and by its aid they determined the ordinates or coefficients intermediate to those directly given by experiment. In this manner the authors were enabled to arrange a large table of coefficients for each orifice, from which we extract the following;—

Head on centre of Orifice.	Height of Orifices (base of each 7·874 inches).					
	7·874 in.	3·937 in.	1·968 in.	1·181 in.	·787 in.	·394 in.
inches.						
·394						0·709
·787					0·660	0·698
1·181				0·638	0·660	0·691
1·575			0·612	0·640	0·859	0·685
1·968			0·617	0·640	0·659	0·682
2·362		0·590	0·622	0·640	0·658	0·678
3·150		0·600	0·626	0·639	0·657	0·671
3·937		0·605	0·628	0·638	0·655	0·667
4·725	0·572	0·609	0·630	0·637	0·654	0·664
5·906	0·585	0·611	0·631	0·635	0·653	0·660
7·874	0·592	0·613	0·634	0·634	0·650	0·655
11·811	0·598	0·616	0·632	0·632	0·645	0·650
15·748	0·600	0·617	0·631	0·631	0·642	0·647
feet.						
1·640	0·602	0·617	0·631	0·630	0·610	0·643
2·297	0·604	0·616	0·629	0·629	0·637	0·638
3·281	0·605	0·615	0·627	0·627	0·632	0·627
4·265	0·604	0·613	0·623	0·623	0·625	0·621
5·250	0·602	0·611	0·619	0·619	0·618	0·616
6·582	0·601	0·607	0·613	0·613	0·615	0·613
9·843	0·601	0·603	0·606	0·607	0·608	0·609

All the numbers in this Table are the respective values of *m* in the formula $Q = m S \sqrt{2 g H}$. But those which in each column are found above the transverse line, are not the true coefficients of reduction from the theoretic to the actual discharge, as we shall presently see.

Glancing over the numbers of each column, we see that they increase as the head increases, but only up to a certain point, beyond which they diminish, although the head still augments. However, in small orifices, those below 1·181 in., the increasing part of the series is very limited; and even in very small ones it is nothing. We see also that the terms of the decreasing part of all the series approach equality in proportion as the head increases in value.

Although the coefficients in the Table above are deduced from experiments made on rectangular orifices, they may serve for all others, whatever be their form; the height of the rectangle noted in the Table will express the smallest dimension of the orifice which should be used. For it is generally admitted that the discharge is entirely independent of the figure of the orifice, and that it always remains the same, while the area of the opening is unchanged; always provided, in accordance with an observation made by M. Hachette, that this figure presents no re-entrant angles.

Although some of the orifices on which Poncelet and Lesbros made their experiments are very large, still there are those which discharge twenty or thirty times as much water; such are the openings of sluice-gates in canals of navigation, and it was important to establish directly the coefficient of their discharge. In 1782 Lespinasse, a skilful engineer, made for this purpose several experiments on the canal of Languedoc, to which, ten years after, Pin, engineer of the same canal, added some others. The principal results of these, like the former, are placed in the following Table. The breadth of the opening is nearly 4·265 ft.; the form not being exactly a rectangle, the heights are to be regarded as only approximate.

Openings.		Head on the centre.	Discharge in one second.	Coefficient.
Area.	Height.			
square feet.	feet.	feet.	cubic feet.	
7·745	1·805	14·554	145·292	·613
6·992	1·640	6·631	92·635	·641
6·992	1·640	6·247	88·221	·629
6·466	1·509	12·878	138·937	·641
6·723	1·575	13·586	128·764	·617
6·723	1·575	6·394	83·948	·616
6·723	1·575	6·217	79·857	·594
6·717	1·575	6·480	85·219	·621
		Mean term		·625

This mean coefficient, exactly equal to that obtained from an experiment made on a sluice of the basin of Havre, is a little greater than that indicated by the table of M. Poncelet, p. 1893; probably the cause of it is, that on all the perimeter of the opening, the flowing did not occur as in a thin side, and that on some point the contraction was suppressed. It may be remarked on this subject that the woodwork which surrounded this orifice was $0^{m}\cdot 27 = \cdot 886$ ft. thick, and even $0^{m}\cdot 54 = 1\cdot 772$ ft. thick on the lower edge. Also, when the gate was raised only a small quantity, the contraction ceased on the four sides, and the coefficient increased considerably. For example, Lespiousse having raised the gate only $0^{m}\cdot 12 = \cdot 394$ ft., had for a coefficient ·803, while with 1·509 ft. opening, he had a coefficient of only ·641.

The experiments of this engineer presented a very remarkable fact, of which no mention was made, and which reappeared in those of Pin. A sluice-gate had two parts, and each had an opening in it: if, while the water was flowing through one, the second was opened, the discharge of the first was diminished; if both were opened together, the discharge was not double of the two taken separately, although each had the same area and head. The difference is about one-eighth, as may be seen by the annexed comparison of the coefficients of reduction for the two cases.

Coefficient	
With one opening.	With two openings.
0·641	0·550
0·689	0·555
0·616	0·554
0·594	0·526
0·621	0·555
0·620	0·548

The interval between the two openings is $2^{m}\cdot 92 = 9\cdot 58$ ft., and their plane forms an angle of 60° with the direction of the canal.

But it is very worthy of remark that this fact, which appeared positive for the sluices of the canals, did not take place at all in a series of experiments which M. Castel and D'Aubuisson de Voisins made on a small scale, but with very great care, for the purpose of verifying it. They had, side by side, three rectangular orifices of ·328 ft. by ·033 height, and separated by an interval of only ·033 ft. They measured the water passing the middle orifice first, keeping the two side orifices closed, then opening one and finally opening both; the mean results are given in the following Table;—

Head on the Orifice.	Discharge from Middle Orifice.			Coefficient.
	Middle Orifice alone open.	Middle Orifice, with 1 Lateral Orifice, open.	Middle Orifice, with the 2 Lateral Orifices, open.	
feet.	cubic feet.	cubic feet.	cubic feet.	
·0656	·01607	·01606	·01614	0·728
·0984	·01946	·01946	·01942	0·720
·1312	·02242	·02246	·02250	0·719
·1640	·02497	·02497	..	0·715
·1969	·02723	·02716	..	0·710

Supposing that these unexpected coefficients might have been influenced by the very small interval from one orifice to the other, we increased the interval fivefold; that is, from ·394 in. to 1·968 in., and the coefficients remained the same.

Surprised at the difference between these results and those found on the canal of Languedóc, and fearing that it arose from the particular form of the orifices and apparatus, D'Aubuisson requested M. Castel to make new experiments; and in 1836 he had the kindness to perform a series, by the aid of the great apparatus which he had just been using for his great work on Weirs. He dammed up a canal $0^{m}\cdot 74 = 2\cdot 428$ ft. broad, with a thin copper plate, in which he opened, on the same horizontal strip, three rectangular orifices, each 3·94 in. wide by 2·36 in. high, and separated from each other by an interval of 3·15 in. The flowing took place under a constant head of 4·213 in. above their centre, and the coefficients of contraction were as follows;—

One orifice open	for the middle	·6198
	" right	·6193
	" left	·6194
Two orifices open	the two outsides	·6205
	middle and right	·6205
	" " left	·6207
The three orifices all open	.. ..	·6230

Here, in proportion as the orifices were open, instead of a diminution in the coefficients, there was an increase, very small, to be sure. As it depended on a particular cause, a greater velocity of water in the canal, in consequence of a greater discharge, we shall make deduction of that, and conclude that, when in the dam of a reservoir or course of water new orifices are opened by the side of an orifice already existing, the discharge through that orifice is not diminished by it. Some persons thought that such a consequence would not extend to the case when two orifices were situated in planes making a certain angle, as in the openings of the sluice-gates. M. Castel solved this question. He took two plates joined at an angle of 120° (that of sluice-gates is generally from 10° to 20° more open); in each he made two rectangular orifices of 3·94 in. wide by 2·36 in. high; one 4·72 in. and the other 11·02 in. distant from the angle that joined them; he fitted this partition to the extremity of his canal, and let the water flow under a head of $0^{m}\cdot 14 = 5\cdot 51$ in. He first opened successively each of the four orifices; then two at a time differently combined; then three differently combined, and finally four. The following Table presents the mean results obtained.

No. Orifices.	Coefficient.
1	·618
2	·619
3	·620
4	·622

That given in the second line was obtained by the two extreme orifices, which were disposed like those of the sluice of the canal of Languedoc. As a last objection, it was said that the heads at the sluice of the canal of Languedoc were from $2^m = 6\frac{1}{2}$ ft. to $4^m = 13$ ft. To obtain an analogous case, M. Castel adapted to the experimental apparatus two orifices of 1·97 in. wide by 1·18 in. high, and had the results which we give, p. 1902.

Head.	No. Orifice.	Coefficient.
3·379 ft.	1	·621
	2	·622
6·693 ft.	1	·619
	2	·621

It is always the same coefficient, with the insignificant increase due to the number of orifices open.

These experiments, often repeated, with apparatus free from every exceptionable circumstance, and where any sensible error was impossible, by the most accurate and conscientious observer, induced D'Aubuisson de Voisins, if not to call in doubt the facts previously announced, at least to regard them as anomalous, and to reject the general consequence which may be drawn from them.

In the different cases hitherto investigated, it is admitted that the fluid of the reservoir arrives equally at all parts of the orifice, but often it is not so; for example, when the orifice is at the bottom of a vertical side, and its lower edge is in the plane of the bottom of the reservoir, the contraction is then destroyed on that side, and consequently the discharge is greater. What will be the increase in discharge for a certain length of suppression in the contraction? This question has been nearly solved by M. Bidone, by the aid of numerous experiments made for that purpose at the water-works of Turin.

The orifices were made in thin vertical copper plates; on their interior surface were fixed, perpendicular to their plane, small plates, on a level with certain sides of the orifice; as it were, the prolonging of these sides into the interior of the reservoir. During the flowing, the water running along the plates passed through the adjacent sides without any contraction, while a contraction occurred on the other sides. The form and size of these orifices were various. We shall limit ourselves to giving the results of experiments with a rectangular orifice of $0^m·054 = 2\frac{1}{8}$ in. base and 1·06 in. in height; the plates adapted to them, sometimes on one side and sometimes on two or three, were 2·638 in. long; they thus extended that length into the reservoir. The flowing having been produced under heads varying from 6·562 ft. to 22·573 ft., we have the following coefficients;—

The contraction being suppressed on	Part of Orifice without contraction.	Coefficient.	Ratio.
Neither side	0	·608	1·000
A small „	$\frac{1}{6}$	·620	1·020
A great „	$\frac{2}{6}$	·637	1·049
A great and a small	$\frac{3}{6}$	·659	1·085
Two small and one great ..	$\frac{4}{6}$	·680	1·112
Two great and one small ..	$\frac{5}{6}$	·692	1·139

M. Bidone, taking the mean result of all the experiments made on rectangular orifices, admits for the numbers of the last column, which indicates the increase of the coefficient and consequently of the discharge, that for the orifice entirely free being taken for unity, the general expression $1 + 0·152 \frac{n}{p}$, in which n represents the length of the part of the perimeter when the contraction is suppressed, and p the length of the whole perimeter. The greatest error which this formula gave M. Bidone being only $\frac{1}{30}$, we may adopt for the value of the discharge in rectangular orifices when there is no contraction on a part of the perimeter, $m\,S\sqrt{2\,g\,H}\left(1 + 0·152\frac{n}{p}\right)$.

The same author also made experiments on circular orifices. He took one of 1·575 in. diameter, and by the aid of curved cylindrical plates he destroyed the contraction, first, on an eighth of the circumference; then successively on 2, 3, 4, 5, 6, and 7 eighths. We indicate the results obtained in the following Table;—

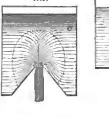
$\frac{n}{p}$	Coefficient.	Ratio.	$\frac{n}{p}$	Coefficient.	Ratio.
0	0·597	1·000	$\frac{4}{8}$	0·639	1·072
$\frac{1}{8}$	0·603	1·011	$\frac{5}{8}$	0·649	1·087
$\frac{2}{8}$	0·615	1·032	$\frac{6}{8}$	0·664	1·112
$\frac{3}{8}$	0·625	1·048	$\frac{7}{8}$	0·670	1·123

We see here that the numbers of the last column increase a little less rapidly than in the case of the rectangular orifices, so that the general expression from these numbers would be only $1 + 0·128 \frac{n}{p}$.

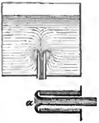
M. Bidone, after having circumscribed seven-eighths of his circular orifice, wished to circumscribe it entirely; and for this purpose he fitted to the orifice a cylindrical tube of $0^{m}\cdot04 = 1\cdot575$ in. diameter, which ran $0^{m}\cdot067 = 2\cdot638$ in. into the interior of the reservoir; he had 0·767 for the coefficient, and consequently 1·285 for the number of the last column. The expression above would have given 1·128—a number in which the increase is not even half of that really obtained. Whence we conclude that the phenomena of flowing through interior tubes, the case where the contraction is entirely suppressed at the edges of the exterior orifice, is no longer of the same kind as that where it is destroyed only in part, however great that part may be; there is no passing from one case to the other.

We have always supposed the sides in which the orifices were, to be plane, but they may be of another form. To give an idea of the effect which may result upon the product of the flowing, it is necessary to remember that if the fluid lines arrive at the orifice parallel to each other, the actual discharge would be equal to the theoretic discharge, and that it is less only in consequence of the obliquity with which they unite, from which obliquity necessarily results, at the point of contact, the destruction of a part of the motion acquired. This being established, if around the orifice we imagine a spherical surface or cap, Fig. 4005, of a radius equal to that of the sphere of activity of the orifice, and limited by the sides of the vessel, it would be traversed at each of its points, and in a direction nearly perpendicular, by the arriving lines; the more extended the spherical cap, the more oblique will be their directions, and the more opposed to each other; and consequently the more will their motion be destroyed at the orifice, and the less considerable the discharge. When the side is plane, the cap is the surface of a hemisphere, Fig. 1001, and is found in the case to which belong the coefficients of discharge just given. But if it is disposed in the form of a funnel, or if it is simply concave towards the interior of the vessel, then the cap is smaller and the discharge greater, without, however, exactly following the ratio of the spherical surface. If, on the contrary, the side is convex, the product is less; it will be smaller still in the case represented, Fig. 4005. Finally, it would be a *minimum* if the cap became an entire sphere; and this would happen if it were possible to transport an orifice to the middle of the fluid mass enclosed in the vessel.

4005.



4006.



That profound mathematician Borda succeeded in almost entirely realizing this case. He introduced into a vessel a tin tube $0^{m}\cdot135 = 4\cdot43$ ft. long and $0^{m}\cdot032 = \cdot105$ ft. diameter; and under a head of 0·820 ft. he caused the flowing to take place in such a manner that the effluent water in no way touched the sides of the tubes, Fig. 4006; the actual discharge was only 0·515 of the theoretical discharge, and several considerations led Borda to admit that it might have been reduced to ·50.

Having afterwards surrounded the orifice of entrance of the tube with a large border, thus putting it, although in the middle of the fluid, into the same circumstances as when it is perforated through a thin side of a vessel, the coefficient was raised to 0·625. He might have obtained the same result by employing simply a tube with very thick sides.

If the sides of the tube had a sensible thickness, without being too considerable, 0·394 in. or even 0·788 in. for example, and were also cut quite square off at the extremity, so that the zone formed by the thickness should be plane, with sharp edges, the fluid winding round the exterior edge would enter the tube without touching the rest of the zone, Fig. 4006, *a*; so that every part of the side inside of the exterior surface would be without effect, and the flowing would take place as if that surface alone existed. This therefore will be its diameter; that is to say, the exterior diameter of the tube, which must be introduced into calculations relating to interior tubes. By taking this, Bidone found, by two experiments, that the action of the vein running in the tubes without touching the interior, was very nearly half the section of the tube, and that the coefficient of contraction was nearly 0·50.

Thus 0·50 and 1 will be the limits of the coefficients of contraction; limits which may be approached very nearly, but never quite attained. For orifices in a plane side, they seldom descend below ·60 or rise above ·70; and even in ordinary practice, they are confined between ·60 and ·64; as a mean approximate term, ·62 is usually taken, and we have,

$$\text{In mètres, } Q = 0\cdot62\,S\sqrt{2g\,H} = 2\cdot75\,S\sqrt{H} = 216\,d^2\sqrt{H};\ \text{or,}$$
$$\text{In feet, } Q = 0\cdot62\,S\sqrt{2g\,H} = 4\cdot974\,S\sqrt{H} = 3\cdot9066\,d^2\sqrt{H},$$

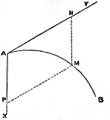
d being the diameter of a circular orifice.

In the velocity with which water flows from orifices in a thin side, as we have admitted exactly that due to the head of the reservoir, is it $\sqrt{2\,g\,H}$? We will examine it.

We may ascertain the velocity with which water runs from an orifice, by the height to which a vertical jet, starting from that orifice, is thrown; it is at least $\sqrt{2\,g\,h}$, *h* being that height. Now, from what is known respecting *spouting fluids*, *h* differs from H only 1, 2, 3, &c., hundredths of the square of its value, according as H is 1^{m}, 2^{m}, 3^{m}, &c.; and the velocities being as the square roots of the heights, the *actual* velocities will differ in the same cases only 1, 2, 3, &c., half-hundredths of the *theoretic velocity*. Another mode of determining the actual velocity indicates still less difference. We will present it before making an application of it.

When a body is thrown in any direction A Y, Fig. 4007, with a certain velocity, by the combined influence of that velocity and of gravity, it describes a curve A M B.

4007.

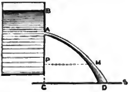


Olivor Byrne, the compiler and editor of this Dictionary has, for the first time, in this work, cleared up all the difficulties connected with this curve A M B; hence it is unnecessary to dwell upon this matter here. In the present article we confine ourselves to what concerns the fundamental principle which we employ; and treat of that *parabola* which coincides most nearly with the curve A M B, Fig. 4007. See DAMMING, p. 1126; and GUNNERY.

Let v be the velocity with which a body is impelled along A Y, and t the time spent in arriving at N, in this direction, if the force of projection acted alone upon it; the motion would then have been uniform, and we should have had $A N = v t$; on the other hand, had the body been subjected to the action of gravity alone, it would have descended from A to P during the same time, so that we should have had $A P = \frac{g t^2}{2}$. Draw the parallelogram A P M N; at the end of the same time it really will arrive at M, and will have described the arc A M; A P will be its *abscissa*, and M P, parallel to the axis A Y, wil be its *ordinate*. Call the first of these lines x and the second y, we shall have $x = \frac{g t^2}{2}$ and $y = v t$; in this latter equation, taking the value of t, and substituting it in the first, we have $x = \frac{g y^2}{2 v^2}$, or $y^2 = \frac{2 v^2 x}{g}$; or, calling h the height due to the velocity v, and recollecting that $\frac{v^2}{2 g} = h$, $y^2 = 4 h x$; an equation of a parabola of which $4 h$ is the parameter. Hence *a heavy body, impelled by any force of projection, describes a curve which resembles a parabola whose parameter, in the case of a jet of water, may be taken without involving much error, equal to four times the height due to the velocity of projection.*

What we have just said of a body in general is applicable also to every jet of water issuing from an orifice. If this orifice is in a vertical side, the axis of projection being horizontal, the ordinates will be horizontal; they will be the distances of the different points of the jet from the vertical, let down from the centre of the orifice; and if through any point c of that vertical, we imagine a horizontal plane, the distance C D, Fig. 4008, is called the *reach of the jet* on that plane. According to our theorem, the square of this range, or in general of a distance M P, divided by four times its corresponding perpendicular A P, will give the height due to the velocity of exit $\left(h = \frac{y^2}{4 x}\right)$; and consequently we shall have for this velocity, $v = \sqrt{2 g h} = 2{\cdot}215 \frac{y}{\sqrt{x}}$ in mètres, or $4{\cdot}0113 \frac{y}{\sqrt{x}}$ in feet.

4008.



By following this mode of determination, Bossut, in two experiments, found 0·974 and 0·980 for the ratio of the actual to the theoretic velocity. Michelotti having caused jets to issue from each of the three stories of the tower of his hydraulic establishment through a vertical orifice 0·889 ft. diameter, obtained the results given in the following Table;—

Head.	Jet.		Velocity.		Ratio.
	Abscissa.	Range.	Real.	Theoretic.	
feet.	feet.	feet.	feet.	feet.	
7·513	20·615	24·706	21·819	21·983	·993
12·894	15·289	27·724	28·446	28·807	·988
23·590	4·626	20·506	38·289	38·978	·983

The difference between the two velocities increases with the head. It should be so, since the cause of this difference, the resistance of the air, increases as the square of the velocity, and consequently nearly as the head.

If the water contained in the reservoir, instead of being at rest, were animated with a velocity which carried it towards the orifice; for example, if the basin having a small section were fed by a course of water which came directly to the side on which the orifice is open, the fluid particles would go out, not only in virtue of the pressure exerted by the fluid mass above, but also in virtue of the velocity which they had at the moment of entering the sphere of activity of the orifice; we should thus have to add to the head measuring the pressure, a new force, which will be the head generating that velocity. Thus, if u represent that velocity, we shall have

$$Q = m S \sqrt{2 g \left(h + \frac{u^2}{2 g}\right)} = m S \sqrt{2 g h + u^2}.$$

Example.—There is a basin 65·62 ft. long, 6·562 ft. broad, and 3·281 ft. depth of water; at one extremity is a dam of plank, with a rectangular opening 1·804 ft. wide by 1·181 ft. high; its sill or lower edge is 2·986 ft. below the level at which the water is constantly kept in the basin; it is supplied by a stream arriving at the other extremity. What is the discharge?

We have $S = 1{\cdot}804 \times 1{\cdot}181 = 2{\cdot}131$ sq. ft.; $h = 2{\cdot}986 - \frac{1{\cdot}181}{2} = 2{\cdot}396$; m, according to the Table, p. 1893, supposed to be prolonged, will be about 0·600; as to u, it will be given by one of the means to be indicated hereafter. In a great number of cases we can regard it as being the mean velocity of the water in the basin, a velocity to be determined as follows: the discharge Q, taken at first by neglecting u will be $0{\cdot}600 \times 2{\cdot}131 \sqrt{64{\cdot}364 \times 2{\cdot}396} = 15{\cdot}878$ cub. ft. When the water runs in a canal, we have $Q = Su$; dividing then the value of Q found, by the section (of the basin) 21·53, we find $u = {\cdot}73748$, the square of which is ·54389. Putting this value into the general expression of the discharge, we have $0{\cdot}600 \times 2{\cdot}131 \sqrt{64{\cdot}364 \times 2{\cdot}396 + {\cdot}5439} = 15{\cdot}906$ cub. ft. Joseph Bennett, the American translator of D'Aubuisson's work on Hydraulics, observes, that here D'Aubuisson's book has an error in taking the section of the orifice, instead of the section of the basin, and also another error in solving the example. What is here given is supposed to be what D'Aubuisson intended.

The difference between these two results may be entirely neglected. The effect of the velocity u has been almost nothing; in most cases it will be so.

Very often the water at the exit of the orifices made in the side of a reservoir is taken and conducted by canals or channels, uncovered on the upper part, the bottom of which as well as the sides agree with the lower edge and sides of the orifice, which are thus in the planes of the bottom and sides respectively. MM. Poncelet and Lesbros determined, by a great number of experiments, the coefficients of the discharge for such canals, which they fitted to orifices on which they had already made the fine observations whose results we have recorded; the canals varied in form, inclination, and position. The last of these philosophers communicated to D'Aubuisson a part of the results given by a rectangular canal $3^m = 9{\cdot}843$ ft. long and $0^m{\cdot}20 = {\cdot}656$ ft. broad, like all its orifices. The reservoir in whose side the orifices were, was $3^m{\cdot}68 = 12{\cdot}074$ ft. broad. The canal was first placed at an equal distance from the two sides of the reservoir and $0^m{\cdot}54 = 1{\cdot}772$ ft. above the bottom; it was kept horizontal; it is canal No. 1 of the following Table. We here give the coefficients m of the formula $mS\sqrt{2gH}$, which MM. Poncelet and Lesbros obtained, and place them opposite those which they had obtained previously with the same orifices, when the water flowed freely into the atmosphere.

Height of Orifice.	Head on Orifice.	Coefficient.			Height of Orifice.	Head on Orifice.	Coefficient.		
		Without Canal.	With Canal				Without Canal.	With Canal	
			No. 1.	No. 2.				No. 1.	No. 2.
feet.	feet.				feet.	feet.			
·6562	4·2850	0·604	0·601	0·601		·1542	0·647	0·495	0·493
	3·1235	0·605	0·602	0·599		·1181	0·612	0·452	0·443
	1·3124	0·600	0·591	0·580	·0984	4·4261	0·622	0·622	
	·7940	0·596	0·559	0·552		1·5289	0·630	0·629	
	·4003	0·572	0·483	0·482		·6792	0·634	0·632	
·3281	4·4490	0·643	0·614			·2658	0·639	0·633	
	3·3040	0·645	0·644			·2067	0·640	0·627	
	1·5814	0·647	0·615			·1870	0·640	0·640	
	·5282	0·641	0·590			·1214	0·639	0·541	
	·3740	0·608	0·562		·0328	·4449	0·620	0·621	0·660
	·2887	0·602	0·523			3·2580	0·627	0·631	0·665
	·1969	0·590	0·459			1·6307	0·643	0·648	0·671
·1640	4·7935	0·621	0·624	0·627		·6398	0·655	0·665	
	3·5468	0·627	0·626	0·628		·4167	0·664	0·669	
	1·6350	0·631	0·625	0·624		·2494	0·674	0·671	0·680
	·6956	0·634	0·631	0·615		·1378	0·684	0·640	
	·3478	0·629	0·614	0·597					

By comparing the coefficients of the third and fourth columns, allowing for the inevitable errors in observation, and excepting the orifice of 0·328 ft., we see that so long as the heads taken above the centre of the orifice were from 2 to 2½ times greater than the height of that orifice, the canal had no marked difference in the discharge; the discharge was the same as if no canal were there. But in small heads, the discharge diminished perceptibly, and as much more so as the head was less; the diminution has reached a quarter, and even more.

This difference in great and small heads appears to proceed from the fact that, with the former, the fluid, rushing forth as into the air, is not influenced by the resistance of the sides. The canal, says Lesbros, has no influence, except when the head is not great enough to detach the fluid jet at its exit from the orifice entirely from the bottom (and sides) of this canal.

The same canal was then placed, as is often done in practice, in such a manner that its floor was at the level of the bottom of the reservoir, and was, in fact, a prolonging of it. It was natural to suppose that the contraction being then suppressed on the lower edge of the orifice, the coefficient of discharge would be greater; but generally, and the orifice of ·0328 ft. still excepted, it was less, particularly with small heads, as was seen in the above Table, where the canal, in its new position, is designated by No. 2. Other circumstances, perhaps the resistance of the bottom of the reservoir, which may have diminished the velocity of arrival, perhaps the less facility which the fluid sheet had in raising itself above the sill at the entrance of the canal, will have more than compensated for the diminution in the contraction.

In withdrawing the canal from the middle of the reservoir, and placing it nearer one of the sides, this diminution took place in part, and a small increase in the discharge was obtained. The canal was then inclined, leaving it in other respects in the position it last had. When the inclination was $\frac{1}{100}$ or 34′, the coefficients were sensibly the same as when the canal was horizontal. But when the inclination was carried to $\frac{1}{10}$, or 5° 44′, the coefficients were increased from 3 to 4 per cent., as seen in the following Table;—

Height of Orifice.	Head on Orifice.	Coefficients, with the Canal	
		Horizontal.	Inclined.
feet.	feet.		
·0443	1·1188	·660	·691
·0666	1·1123	·654	·681
·1555	·6890	·616	·639
·1775	·6660	·612	·636

Cylindrical Ajutages.—Cylindrical ajutages, called also *additional tubes*, as we have seen, give a more considerable discharge than orifices in a thin side, the head and area of the opening remaining the same. But in order to produce this effect, it is necessary that the water entirely fill the mouth of the passage; it is commonly so, when the length of the tube is two or three times its diameter. If it is less, it often happens that the fluid vein, which is contracted at the entrance of the tube, does not again increase and fill the interior; the flowing then takes place in all respects as through a thin side; this is always the case when the length of the tube is less than that of the contracted vein, and consequently is only half, or less than half the diameter.

The coefficient of reduction from the theoretic to the actual discharge, through an additional tube, presents a few variations, as may be seen in the following Table;—

Observer.	Tube.		Head.	Coefficient.
	Diameter.	Length.		
	feet.	feet.	feet.	
Castel	·0509	·1312	·6562	·827
„	·0509	·1312	1·5749	·829
„	·0509	·1312	3·2478	·829
„	·0509	·1312	6·5620	·829
„	·0509	·1312	9·9414	·830
Bossut	·0755	·1772	2·1326	·788
„	·0755	·1772	4·0684	·787
Eytelwein	·0853	·2559	2·3623	·821
Bossut	·0886	·0341	12·6318	·804
„	·0886	·1772	12·6975	·804
„	·0886	·3543	12·8615	·804
Venturi	·1345	·4200	2·8873	·822
Michelotti	·2658	·7087	7·1526	·815
	square.			
„	·2658	·7087	12·4678	·803
„	·2658	·7087	22·0155	·803

The mean of the coefficients, abstracting the first two of Bossut, manifestly anomalous, is 0·817; ·82 is generally taken, and we have

$$Q = \cdot 82\,S\sqrt{64\cdot364\,H} = 6\cdot5786\,S\sqrt{H} = 5\cdot1668\,d^2\sqrt{H}.$$

Since the jet in a full tube runs out in lines parallel to the axis of the orifice, and consequently its section is equal to that of the orifice, the diminution of the discharge can arise only from a diminution in the velocity; and the ratio of the actual to the theoretic discharge will also be that of the actual to the theoretic velocity, as is seen by the following results of three experiments cited in the above Table; one of Venturi and two of M. Castel;—

Jet.		Velocity.		Coefficient	
Abscissa.	Ordinate.	Real.	Theoretic.	Of Velocity.	Of Discharge.
feet.	feet.	feet.	feet.		
4·796	6·128	11·204	13·628	·824	·822
1·791	2·208	6·6175	7·959	·832	·827
3·7402	5·803	12·037	14·481	·832	·829

Thus we may admit that the velocity of a jet, at its passage from a cylindrical tube, is only 0·82 of that due to the height of the reservoir; and the height due to the velocity of the jet will be only ·67 (= $\cdot82^2$) of that due to the height of the reservoir, since the heights or heads are supposed to be as the squares of the velocities.

In the hypothesis of the parallelism of the sections, the principle of the *vis viva:* that the quality of action developed by the motive force, during a certain time, is equal to half the increase or diminution of the *vis viva* during that time—this principle gives for the velocity v of the water passing from a short prismatic tube, of which S is the section, and which is terminated by an orifice whose section s is smaller than the preceding, m and m' being the coefficient of contraction for these sections respectively

$$v = \sqrt{\frac{2\,g\,\mathrm{H}}{1 + \left(\frac{m'\,s}{\mathrm{S}}\right)^2 \left(\frac{1}{m} - 1\right)^2}};$$

and for the case of our additional tubes entirely open at their extremity, and consequently where $s = \mathrm{S}$ and $m' = 1$,

$$v = \sqrt{\frac{2\,g\,\mathrm{H}}{1 + \left(\frac{1}{m} - 1\right)^2}}.$$

If it be admitted that the contraction at the entrance of the tube is the same as in the orifices in a thin side, that is to say, if we make $m = \cdot62$, we have $v = 0\cdot855\sqrt{2\,g\,\mathrm{H}}$ and $\mathrm{Q} = \cdot855\ \mathrm{S}\sqrt{2\,g\,\mathrm{H}}$; with $m = \cdot65$, it would be $\mathrm{Q} = \cdot0885\,\mathrm{S}\sqrt{2\,g\,\mathrm{H}}$.

The fluid vein, after its contraction at the entrance of the additional tube, tends to take and preserve a cylindrical form, whose section would be that of the contracted vein; and consequently it tends to pass out without touching the sides of the tube; but some lines of water are carried towards the sides, either by a divergent direction, by an attractive action, or by the two causes united. As soon as they arrive in contact, they are strongly retained by the molecular attraction, that which produces the ascension of water in capillary tubes; by an effect of this same force they draw the neighbouring lines, and by degrees the whole vein, which then rushes out, filling the tube, and passes through the contracted section more rapidly. Such appears to be the physical cause of the increase of discharge due to tubes.

The immediate cause is the contact; and all the circumstances which cause the contact, or which favour it, will produce that increase.

Among these circumstances we will notice;—

1st. The length of the tube; the longer it is, the more chances it will present for contact; there will be no contact when the length is less than that of the contracted vein.

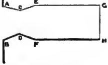
2nd. A small velocity; the fluid lines will then be less forcibly retained in the direction of the primitive motion; they will deviate and approach the sides with more facility. M. Hachette, in his experiments made on this subject, succeeded, by augmenting the head and consequently the velocity, in detaching a vein from the side it was following. On the contrary, by diminishing the head, allowing it, however, a head of 0·9843 ft., he succeeded in making the tube more full, the length of which was 0·01968 ft., and its diameter 0·03117 ft.

3rd. The affinity of the material of the tube, or rather its disposition to be more readily moistened. Thus, by rubbing tallow or wax on the sides, the water will not follow them as it did before. Hachette, by covering an iron tube with an amalgam of tin, caused mercury to run out with a full tube, which did not take place before the coating. The interposition of air, or its arrival in a tube, is sufficient to detach the fluid vein from it. Venturi, after having fitted to a vessel full of water, a tube of $0^{\text{m}}\cdot0406 = \cdot1332$ ft. diameter and $0^{\text{m}}\cdot095 = \cdot3117$ ft. length, perforated near the middle and quite round its perimeter, with a dozen small holes; when the flowing took place, not a drop of water passed through these holes, nor did the water touch the sides. The holes were then successively stopped, and the same results continued; but when all were closed, the vein filled the tube, and the discharge was increased in the ratio of 31 to 41. M. Hachette, on repeating the experiments and closing the holes with caution, saw the vein continue to pass out without touching the side; but a slight agitation was then enough to produce contact, and to produce a flow with the full tube.

It is more than a century since Poleni made known the singular effects of cylindrical tubes, and the investigation of the cause has been a serious study with philosophers.

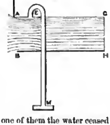
It was generally said, since the convergence in the direction of the fluid lines, on their arrival at the orifice, produces a contraction in the fluid vein, there will also be a contraction at the entrance of the tube; but in consequence of the attractive action of the sides, the contraction will be less, and the discharge will consequently be greater. The experiments of Venturi do not allow us to admit of such a cause producing a less contraction.

4009.



That ingenious philosopher opened, in a thin side of a reservoir, an orifice, whose diameter A B, Fig. 4009, was $0^{\text{m}}\cdot0406 = \cdot1332$ ft.; and under a head of $0^{\text{m}}\cdot88 = 2\cdot8873$ ft., he obtained $0^{\text{mmm}}\cdot137 = 4\cdot8384$ cub. ft. of water in 41″. To this orifice he then fitted the tube A B C D, having nearly the form of the contracted vein (he had C D = $0^{\text{m}}\cdot0327 = \cdot1073$ ft., and A C = $0^{\text{m}}\cdot025 = \cdot082$ ft.): under the same head he obtained the same volume of water in 42″. To the first tube he fitted the tube C D H G C, in which G H = E F = A B, and the duration of the flowing, all else being equal, was only 31″. Lastly, Fig. 4010, for all this apparatus he substituted the simple cylindrical tube A B H G of the same length, and also of the diameter ·1332 ft., and the flowing of 4·8384 cub. ft. again took place in 31″.

4010.



Thus, in this simple tube, in which everything went on as in the compound tube, there was or there may have been an equal contraction; and the contraction which necessarily took place in the latter at C D is very nearly equal to that of orifices in a thin side. The effect of the cylindrical tube, therefore, was not to lessen the contraction, but to pass the fluid through the contracted section C D, with a velocity increased in the ratio of 31 to 41. Hence alone the increase of discharge.

Venturi attributed it to an excess in the pressure of the atmosphere on the fluid surface contained in the reservoir, an excess proceeding from a vacuum tending to arise in the part of the tube where the greatest contraction took place. He sought to prove this opinion by several examples, very interesting on other accounts, but he has sometimes generalized the results too much. For example, because in one of them the water ceased to flow with full tube under the receiver of an air-pump, he concluded that the phenomena of additional tubes did not take place in the vacuum, and yet Hachette is certain of having produced them there. This single fact would overthrow an hypothesis, against which other peremptory objections are also raised.

Among the experiments of Venturi is one which presents, in a distinct manner, a very remarkable fact, which Bernoulli had already made known. To a cylindrical tube $0^{m}·0406$ = ·1332 ft. diameter and $0^{m}·122$ = ·4003 ft. long; at E $0^{m}·018$ = ·0591 ft. from its origin, he fitted a curved tube of glass, the other extremity of which was plunged into a vessel M, containing coloured water; the flowing was caused by a head of $0^{m}·88$ = 2·8873 ft.; and the water was raised in the tube $0^{m}·65$ = 2·1326 ft.

In the hypothesis of Venturi, this elevation, joined to the head, would be the height due to the velocity through the contracted section, as the head alone is the height due when there is no additional tube; if it were so, the ratio of the velocities must be as $\sqrt{2·8873}$; $\sqrt{2·8873 + 2·1326}$, or as 31 to 40·9, and experiment has actually given a similar result (31 to 41). But from this fact, peculiar perhaps to the case taken for example, a general principle ought not to be deduced. Moreover, the true cause of the ascension of the coloured water in the tube was indicated more than a hundred years ago by Daniel Bernoulli. That celebrated geometrician, author of the chief part of the theoretical principles of the flowing of water, established the law, that the pressure which a fluid exerts against the sides of a tube in which it moves, is equal to the head minus the height due to the velocity of the motion. It is necessary to remark that in speaking of absolute pressure the weight of the atmosphere should be added to the *head* properly so called; thus, if K represents that weight, that is to say, a column of water equal in weight to that of the column of the barometer, H the head and v the velocity of the fluid at a determined point of the tube, $K + H - ·01553\, v^2$ will be the interior pressure at that point. For the exterior pressure we have K, as on all the other points. In one example, at the place of greatest contraction, where $v = \frac{41}{31} \sqrt{2\, g\, H}$ and H = 2·887 ft., the interior pressure is K + 2·887 − 5·050 = K − 2·163 in feet, it is less by 2·163 ft. than the exterior pressure; the exterior pressure will therefore prevail, and will cause the water to ascend 2·163 ft., and, in general, a quantity equal to its excess over the other.

By neglecting K, which is found both in the value of the interior and exterior pressures, the interior pressure on the same point compared to the other is $H - ·01553\, v^2$; it will be negative whenever the height due to the velocity is greater than the head.

Venturi having placed the same tube $0^{m}·054$ = ·177 ft. from the reservoir, the coloured water was not raised; the height due, $0^{m}·594$ or $0·051\, v^2 - 0·051\, (0·82)^2 g\, H$ in metres, or $·01553\, v^2 - ·01553\, (0·82)^2 g\, H$ in feet, was then smaller than the head 2·8873 ft.; the interior pressure was positive, and consequently there was no ascension. Bennett, the translator of D'Aubuisson, remarks;—Should the reader find difficulty as to the formation of this formula, it will vanish in remembering that the velocity from cylindrical pipes is but $\frac{82}{100}$ of that due to the height of reservoir (or $v = ·82 \sqrt{2\, g\, H}$), and by substituting this value in the equation $H = \frac{v^2}{2\, g}$.

Conical Converging Tubes.—Conical tubes, properly so called—that is to say, those which slightly converge towards the exterior of the reservoir—increase the discharge still more than the preceding; they afford very regular jets, and throw them to a greater distance or height. They are also almost exclusively employed in practice. However, their effects as to the discharge and velocity of projection are much more varied; they change with the *angle of convergence*, that is, with the angle which the opposite sides of the truncated cone constituting the tube, form by their extension.

They are, however, the tubes on which we have the fewest documents. In reference to them, D'Aubuisson knew of only four experiments of Poleni, published at Florence in 1718, and which Bossut gives in his Hydrodynamique; notwithstanding the merit of their author, and although made on a great scale, D'Aubuisson had very strong reasons for doubting their accuracy. Struck by the gap which hydraulics presents in this important part, he projected a series of experiments suitable to fill it.

There are or there may be two contractions of the fluid vein, in running through conical tubes; one interior, or at the entrance of the tube, which diminishes the velocity produced by the head; the other exterior, or at the exit, by which the section of the vein a little below the exterior mouth of the orifice is smaller than the mouth itself. Consequently, if s is the section of the orifice, and

V the velocity due to the head, the real discharge will be $n s \times a' V = n n' S V$; a and a′ being two coefficients to be found by experiment; a is the ratio of the fluid section to the section of the orifice, or the coefficient of the exterior contraction; a′ is the ratio of the actual to the theoretic velocity, or the *coefficient of the velocity;* and $n a'$ is the ratio of the actual to the theoretic discharge, or the *coefficient of discharge.*

The knowledge of the two latter, for the different cases which may present themselves, is sometimes useful in practice, as we shall see in treating of *jets of water;* it is this utility, or rather necessity, of having their value, that is, of knowing the discharge and force of projection of different tubes, which has induced the experimenter to make researches on this subject.

To determine properly the different coefficients in question, and above all, to fix the angle of convergence giving the greatest discharge, D'Anbuisson thought it necessary to subject many series of tubes to experiment; in each, the diameter of the orifice of exit and the length of the tube remaining constantly the same; but the diameter of the entrance, and consequently the angle of convergence, was gradually increased. The water flowed through each under different heads. At each experiment the actual discharge was determined by direct measurement, and the velocity of exit by the mode indicated above; the discharge, divided by S V, would give a n', and the velocity divided by v ($v = \sqrt{2 g H}$), would give a′. The series of a n' would show the discharge corresponding to each angle of convergence, and consequently the angle of greatest discharge; and the series of n' would indicate the progression according to which the velocity increased.

The water-works of Toulouse offered all the desirable facilities for executing such a plan. M. Castel, the hydraulic engineer of that city, was pleased, on the invitation of the Academy of Sciences, to undertake the execution.

In 1831, with a very small apparatus, and under small heads, Castel had made a series of experiments, the details and results of which were published in the Annales des Mines of 1833. In 1837 he resumed and considerably extended his works.

This apparatus consisted principally of a rectangular cast-iron box $0^{m}·41$ = 1·345 ft. long, 1·345 ft. wide, and $0^{m}·82$ = 2·69 ft. high; it received at its lower part, and by means of a great tube, the water coming from a reservoir established more than 29·529 ft. above it and kept constantly full; on the front face of the box is a rectangular opening, ·459 ft. high by ·328 ft. wide; it was closed by a well-finished copper plate, to which were fitted additional tubes, in such a manner that their axes were horizontal. When the box was opened at top, the fluid surface could rise there to about ·689 ft. above that axis. The upper opening is commonly surmounted with short tubes of ·656 ft. diameter, the first of which is ·984 ft. high, and the rest 1·64 ft. high, so that heads of about ·656 ft., 1·64 ft., 3·281 ft., 4·921 ft., 6·562 ft., &c., above the tube subjected to experiment, could be obtained.

By means of two cocks placed, one at the entrance of the water into the box, and the other on the upper part of the tubes which surmount it, a perfectly constant level was obtained.

The tubes which M. Castel used were of brass, as well turned and polished as possible. He had two series of them; in one, the diameter of the exit was ·05086 ft. and the length about ·1312 ft.; in the other, the diameter was ·06562 ft. and the length ·164 ft.

The two diameters of each were measured and re-measured with much care, but the want of an instrument proper to operate accurately with such measures, did not permit of a measurement nearer than $0^{m}·00005$ = 0·002 in. ($\frac{2}{1000}$), and such an error might give an error of half a hundredth in the discharges and coefficients.

M. Castel rarely had them so large. He operated under heads of ·6562 ft., 1·64 ft., 3·281 ft., 4·921 ft., 6·562 ft., and about 9·843 ft.; he measured them with very great exactness. He then gives, as very exact, the volumes of water obtained in a certain time.

To determine the velocities with which the water passed from the tubes, he erected, 3·74 ft. below their axis, a horizontal flooring, in the middle of which was a longitudinal groove ·328 ft. broad, into which the jet passed; its range was measured by means of a graduated rule fixed on the flooring and quite near. This range was the ordinate of the curve described by the jet; ·374 ft. was its abscissa, and from these two ordinates was deduced the velocity of projection. Finally, these velocities could only be taken for heads of 6·562 ft. and less; beyond that the jets were broken, and passed beyond the plane where they could be measured.

The same tube, under heads which varied from 0·689 ft. to 9·941 ft., gave discharges always proportional to $\sqrt{H}$, and consequently the coefficients were sensibly the same. Perhaps they experienced a very slight increase under the head of 9·941 ft. We here give those which were obtained with the pipe of each of the two series which furnished the greatest discharge.

Tube of ·05085 foot diameter.			Tube of ·0656 foot diameter.		
Head in feet.	Coefficient		Head in feet.	Coefficient	
	Of Discharge.	Of Velocity.		Of Discharge.	Of Velocity.
·7054	·946	·963	·6923	·956	·966
1·5847	·946	·966	1·5847	·957	·968
3·2547	·946	·963	8·2646	·955	·965
4·8952	·947	·966	4·9149	·956	·962
6·5817	·946	·956	6·5782	·956	·959
9·9414	·947	..	9·9414	·957	..

As to the coefficients of the velocity, it seemed that they would have been sensibly constant, were it not for the resistance of the atmosphere. But this resistance diminishing the range of the jet, and as much more so as the head was greater, there must be in the calculated coefficients a diminution varying with the head, although in reality there was none in the velocity with which the fluid passed out or tended to pass out. We will now compare together the coefficients, both those of the discharge and of the velocity, obtained with the different tubes of the same series; tubes which, in other respects, differed only in the angle of convergence; for each of them the mean term was taken between the six or five coefficients which were given under the six or five heads nearly equal to those which are noted in the preceding Table.

Ajutage ·05085 foot in diameter.			Ajutage ·0656 foot in diameter.		
Angle of Convergence.	Coefficient of		Angle of Convergence.	Coefficient of	
	Discharge.	Velocity.		Discharge.	Velocity.
° ′			° ′		
0 0	0·829	0·830			
1 36	0·866	0·866			
3 10	0·895	0·894	2 50	0·914	0·906
4 10	0·912	0·910			
5 26	0·924	0·920	5 26	0·930	0·928
7 52	0·929	0·931	6 54	0·938	0·938
8 58	0·934	0·942			
10 20	0·938	0·950	10 30	0·945	0·953
12 4	0·942	0·955	12 10	0·949	0·957
13 24	0·946	0·962	13 40	0·956	0·964
14 28	0·941	0·966	15 2	0·949	0·967
16 36	0·938	0·971			
19 28	0·924	0·970	18 10	0·939	0·970
21 0	0·918	0·971			
23 0	0·913	0·974	23 4	0·930	0·973
29 58	0·896	0·975	33 52	0·920	0·979
40 20	0·896	0·980			
48 50	0·847	0·984			

It follows, from the facts set down in these columns;—That for the same orifice of exit, and under the same head, starting from 0·83 of the theoretic discharge, the actual discharge gradually increases, in proportion as the angle of convergence increases up to 13½° only, where the coefficient is 0·95. Beyond this angle it diminishes, feebly at first, as do all variables about the maximum; at 20° the coefficient is again from 0·92 to 0·93. But afterwards the diminution becomes more and more rapid; and the coefficient would end by being only 0·65, the coefficient of small orifices in a thin side, these orifices being the extreme term of converging tubes, that in which the angle of convergence has attained its greatest value, 180°. The angle of greatest discharge will then be from 13° to 14°.

What can be the reason of this? In the conical tubes the theoretic discharge is altered by two causes, the attraction of the sides, which tends to augment it, and the contraction, which tends to diminish it, by diminishing the section of the vein a little below the exit. From the experiments of Venturi it would seem that the fluid vein, at its entrance into a tube, preserved its natural form, that of a conoid of 18° to 20°; so that the nearer the angle of the tube approached such a value, the nearer its sides will be to the vein, at the moment when, after having experienced its greatest contraction, it tends to dilate, and when it is, as it were, left to their attractive action; this action then being stronger, the discharge will be greater. But on the other hand, already at 10° of convergence, the exterior contraction begins to be sensible and to reduce the discharge; it has reduced it 5 per cent. at 18°; and after that, it will not be extraordinary that the angle of greatest discharge is found between these two values, about 14°.

The tubes of ·0656 ft. diameter at the exit, gave coefficients from one to two hundredths greater than those of the tubes of ·0509 ft. An error of 0·004 in. in the estimate of the diameter of the first set, would afford reason, to a great extent, for that difference; and the experimenter was inclined to admit a cause of that kind. The tubes of ·0509 ft., examined several times, inspired him with more confidence.

In following the coefficients of the velocity they are seen, again starting from the angle 0°, to increase like those of the discharge up to near the convergence of 10°; then they increase more rapidly; and beyond the angle of the greatest discharge, while the others diminish, these continue to increase and approach their limit, 1; they are quite near it at the angle of 50°, and even at 40°. The conical tubes, by their different convergence, form a progression of which the first term is the cylindrical tube, and the last is the orifice in a thin side; their velocity of projection, increasing with the convergence, will therefore vary from that of the additional tube to that of the simple orifice, that is to say, from $0{\cdot}82\sqrt{2gH}$ to $\sqrt{2gH}$.

In comparing the coefficients of the discharge with those of the velocity, or their successive values aa' and a', and dividing the first by the second, we shall have the series of a, or the coefficients of the exterior contraction. From the angle 0° to that of 10°, we have sensibly $a = 1$, and consequently there is no contraction; notwithstanding the convergence of the sides, the fluid particles pass out very nearly parallel to the axis. But beyond 10°, contraction is manifested; it reduces the section of the vein more and more, and it would end by rendering it equal to that which passes from orifices in a thin side, as is seen in this Table;—

Angle.	n.	Angle.	n.
°		°	
8	1·00	40	0·88
15	0·98	50	0·85
20	0·95	100	0·65
30	0·92		

Experience having taught that cylindrical tubes certainly produce all their effect, as to the discharge, when their length equals at least 2½ times their diameter; by analogy, and for the sake of not complicating our results with the action of the friction of the water against the sides, the experimenter fixed the length of conical tubes at about 2½ times the diameter of exit; thus it was ·1312 ft. for those of ·0509 ft. diameter, and ·164 ft. for those of ·0656 ft. diameter. However, to be able to determine the effect of their length, he proposed for the tubes of ·0509 ft. diameter, two other series; in one, the common length would have been ·0984 ft., which may be regarded as the *minimum;* for the other, it would have been ·3281 ft., a dimension quite common in practice.

But this work is yet to be done; still, M. Castel has made some primary trials. For the tubes of ·0509 ft. diameter, he took five ·1148 ft. long, and, taken together, they gave as the coefficient of discharge, 0·938; next, with a length of ·1312 ft., he had as coefficient, 0·936; another tube, ·0984 ft. long, gave 0·941 instead of 0·938; and one of ·0787 ft. indicated 0·931 instead of 0·926; so that here the diminution of length would have a little increased the discharge. But with the tubes of ·0650 ft. diameter the discharge, on the contrary, was increased with the length; the length passing from ·1640 ft. to 0·3281 ft., the coefficient under the angle of 11° 52′ was 0·965; under that of 14° 12′, 0·958; and under 16° 34′, 0·950. Thus the effect of the length of tubes is far from being established; its determination demands other series of experiments.

While waiting for more extensive experiments we will assume, for each of the tubes to be employed, provided extraordinary lengths are not taken, the coefficient in the above Tables corresponding to the angle of convergence, without fear of introducing any error of moment.

As to very great conical tubes, or rather to pyramidal *troughs*, which in mills throw the water on to hydraulic wheels, we have three valuable experiments made by the engineer Lespinasse, on the mills of the canal of Languedoc. The troughs there are truncated rectangular pyramids, having a length of 9·5904 ft.; at the greater base, 2·3984 ft. by 3·199 ft.; at the lesser base, ·4429 ft. by ·6234 ft. The opposite faces make angles of 11° 38′ and 15° 18′. The head was 9·5901 ft.

The first two of the three experiments, the results of which are here given, were made on a mill of two stones, each having its wheel; in the first experiment the water was let on to only a single wheel; in the second it was let on to two at a time.

Discharge.	Coefficient.
cubic feet.	
6·7667	0·987
6·6926	0·976
6·7138	0·979

We see how little such tubes diminish the discharge; the discharge given is only one or two hundredths less than the theoretic discharge.

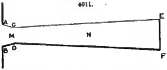
Conical Diverging Tubes.—Of all tubes, those which give the greatest discharge are truncated cones, fitted to a reservoir by their smaller base, and of which the opening for exit is consequently greater than that of entrance. Although very little used, they present phenomena of too much interest to be passed by.

Their property of increasing the discharge was known to the ancient Romans; some of the citizens, to whom was granted a certain quantity of water from the public reservoirs, found by the employment of these tubes, means of increasing the product of their grant; and the fraud became such, that a law prohibited their use; at least, they could not be placed within 52½ ft. from the reservoir.

Bernoulli had studied and subjected to calculation their effects; in one of his experiments he found the real velocity at the entrance of the tube greater than the theoretic velocity, in the ratio of 100 to 108; but to Venturi is principally due our knowledge of the products they can give.

The tubes which he used had a mouth-piece A B C D, Fig. 4011, presenting nearly the form of the contracted vein; A B = ·1332 ft., and C D = ·1109 ft.; the body of the tube C D F E varied in length and flare, the flare being measured by the angle comprised between the sides E C and F D sufficiently prolonged. These tubes were fitted to a reservoir kept constantly full of water; the flowing took place under a constant head of 2·8873 ft., and the time necessary to fill a vessel of 4·8384 cub. ft. was counted as in the experiments of the same author which we have already mentioned.

4011.



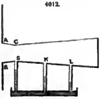
D'Aubuisson gives, in the following Table, the result of the principal observations, after having remarked that the time corresponding to the theoretic velocity was 25″·49.

Ajutage.		Time of Running.	Coefficient.	Observations.
Flare.	Length.			
° ′	feet.			
3 30	·3642	27″5	0·93	
4 38	1·0959	21	1·21	Jet very irregular.
4 38	1·5093	21	1·21	Jet did not fill the ajutage.
4 38	1·5093	19	1·34	To fill ajutage a projecting body introduced.
5 44	·5775	25	1·02	
5 44	·1936	31	0·82	Exit mouth = that of entrance.
10 16	·8662	28	0·91	Jet did not fill ajutage.
10 16	·1476	28	0·91	Jet very regular.
14 14	·1476	42	0·61	Jet detached from sides.

Venturi concluded from his experiments, that the tube of the greatest discharge ought to have a length nine times the diameter of the smaller base, and a flare of 5° 6′; Fig. 4011 represents it; it would give, adds the author, a discharge 2·4 times greater than the orifice in a thin side, and 1·46 times greater than the theoretic discharge. Moreover, he observes, that the dimensions of the tube should vary with the head.

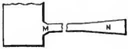
To one of the above-mentioned tubes, that which gave 4·8384 cub. ft. in 23″, he fitted three tubes, and plunged them into a small bucket filled with mercury; the first at the origin D, Fig. 4012, of the tube; the second at one-third of its length, and the third at two-thirds. The mercury was raised respectively ·3937 ft., ·1509 ft., and ·0518 ft.; this would be equivalent to columns of water 5·348 ft., 2·067 ft., and ·7054 ft. According to the theory of Bernoulli, the pressure at the point of greatest contraction D, where the velocity is [illegible] $\sqrt{2g \times 2 \cdot 8873}$ ought to have been $2 \cdot 8873 - 2 \cdot 8873$ ([illegible])$^2 = -5 \cdot 2618$ ft.; the experiment of Venturi gave $-5 \cdot 348$ ft.

4012.



Eytelwein also used diverging tubes in experiments, the results of which are directly interesting in practice. He took a series of cylindrical tubes ·0853 ft. diameter, and of different lengths, which he successively fitted to a vessel full of water; at first separate; then applying to the front extremity the mouth-piece M, which had nearly the form of the contracted vein; then applying to the other extremity the tube M, Fig. 4013, of the form recommended by Venturi; lastly, applying at the same time the mouth-piece and the tube.

4013.



The flowing took place under a mean head of 2·3642 ft. The principal results obtained are given in the following Table.

Here the head was not constant. At each experiment the vessel was filled up to 3·0841 ft. above the orifice, and the fluid was suffered to fall until the surface was only 1·7389 ft. above the orifice; the constant head, which would have given the same discharge in the same time, would have been 2·3642 ft. Let, generally, H′ be that constant head; H the head of the reservoir at the commencement of the flowing, and h that at the end, we shall have $H' = \left(\frac{H - h}{2(\sqrt{H} - \sqrt{h})}\right)^2$.

The occasion to make use of this formula will be presented quite often in practice.

Length of Tube.	Coefficient of discharge of the tube, only according to		Discharge of the tube alone being 1, Discharge	
	Experiment.	Formula of Conduits.	With Mouth-piece.	With Ajutage.
feet.				
·0033	0·62	0·99		
·0853	0·62	0·97	1·56	
·2559	0·82	0·95	1·15	1·35
1·0302	0·77	0·86	1·13	1·27
2·0605	0·73	0·77	1·10	1·24
3·0907	0·68	0·70	1·09	1·23
4·1176	0·63	0·65	1·09	1·21
5·1479	0·60	0·61	1·08	1·17

These experiments show;

1st. The rate according to which the length of the tubes diminishes the discharge; and this, up to a point where the formula for the motion of water in conduit pipes may be applied. The numbers of the third column indicate that this application can take place for small tubes, those under ·0984 ft. diameter, when their length exceeds 6·562 ft. These experiments thus in part fill up the void which existed in our knowledge of additional tubes and conduit pipes.

2nd. That the increase of the discharge proceeding from the flare given to the mouth of entrance of pipes, diminishes in proportion as their length is greater. It were desirable that these experiments had been carried further, for the purpose of knowing what would have been the result of this diminution in large conduits; until this is done, and however small may be the good effect of the flaring at the entrance, it is proper not to neglect it.

3rd. The effect of the flaring at the exit also diminishes in a ratio more rapid still, in proportion as the pipes increase in length. Eytelwein having taken one 20·6 ft. long and of ·0853 ft. diameter throughout, found no difference in the discharge, whether he did or did not use the tube with flaring end.

On fitting this tube immediately to the reservoir, the discharge was 1·18, the theoretic discharge being 1. On fitting it to the mouth-piece, but without the intermediate tube, it rose up to 1·55. The mouth-piece alone gave only 0·92; so that the effect of the tube N added to the mouth-piece M, was to augment the discharge in the ratio of 0·92 to 1·55, or of 1 to 1·69.

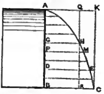
Venturi had that of 19" to 42", or 1 to 2·21. In the two experiments which furnished the terms of this last ratio, the velocities of the water at the passage through the section C D, Fig. 4011, were therefore as 1 to 2·21; and consequently the heights due as 1 to 4·89, since they follow the ratio of the squares of the velocities.

In the experiment which gave the term 1, that where the mouth-piece M alone was used, the actual velocity, which was obtained by dividing the discharge by the section, was 11·9297 ft.; it corresponds to a generating head of 2·2114 ft. The head corresponding to the velocity in the second experiment will then be 2·2114 × 4·89 = 10·8137 ft.; whence it follows that the discharge was equal to what would have occurred if, instead of adding the tube N to the mouth-piece M, the water had been raised in the reservoir, above the level which it had during the flowing, 10·8137 − 2·2114 = 8·6023 ft. Thus the accelerating effect of the velocity due to the diverging tube is measured by a column of water 8·6023 ft.; this is more than a quarter of the weight of the atmosphere. This is a very considerable effect for a force which seems quite small; for we see no other physical cause of the augmentation in the discharge produced by the tube, than the action of the sides, and, in short, the molecular attraction.

On Flowing under very Small Heads.—When the head over the centre of the orifice is very small compared to the height (vertical dimension) of that orifice, the *mean* velocity of the different lines of the fluid vein, that is to say, the velocity which, being multiplied by the area of the orifice, gives the discharge, is no longer that of the central line. It differs from the velocity of the central line as much more as the head is smaller; it will be about a hundredth less if the head is equal to the height, and a thousandth less if the head is three times (3·2) greater than the height. Let us see what theory teaches us in this respect; and first, the law which it indicates for the velocity of the fluid lines, in proportion as the point from which they issue is lower than the level of the reservoir.

Let a vessel be filled with water up to A, Fig. 4014; upon its face A B, which we will suppose vertical for greater simplicity, imagine below each other, a series of small holes, of which B will be the lowest. Designate by H the height A B; the velocity of the line passing out at B will be $\sqrt{2gH}$; and if B C be made equal to that quantity, it will represent that velocity. For every other point P, below the level of the reservoir, the distance A P or x, the line P M, which would represent the velocity of the fluid at its exit from that point, would be $\sqrt{2gx}$, and calling it y, we should have $y = \sqrt{2gx}$. If through the extremity of all these lines P M, a curve be made to pass, they will be its ordinates, and the heights A P or x will be its abscissas; and since $y^2 = 2gx$, this curve may be taken as a parabola having $2g$ or 64·364 ft. for its parameter.

4014.



Thus the velocity of a fluid line passing from a reservoir at any point, is equal to the ordinate of a parabola, of which twice the action of gravity is the parameter, the distance of this point below the level of the reservoir being the abscissa.

Suppose now, that instead of opening a series of small holes on the face A B, there had been perforated in it, from top to bottom, a rectangular slit, of the breadth l; let us find the expression of the discharge.

Divide this opening, in thought, by means of horizontal lines very near each other, into a series of small rectangles. The volume of water which will pass from each of these in a second, or its discharge, will evidently be equal to the volume of a prism which shall have for its base the small rectangle, and for its height the corresponding ordinate. The sum of all these little prisms, or the total discharge, will evidently be equal to another prism, having for its base the parabolic segment A B C M A, and for its height or thickness, the width of the slit. Now, according to a property of the parabola, this segment is two-thirds of the rectangle A B C K, whose surface is $AB \times BC = H \times \sqrt{2gH}$. Thus the discharge through the rectangular opening of which H expresses the height and l the breadth, is $\frac{2}{3} l H \sqrt{2gH}$.

We now seek the discharge through a rectangular orifice open on the same side, but from B to D only, and having the same breadth l; call h the head A D, on the upper edge of the orifice; the discharge of the slit which we suppose from A to D would also be $\frac{2}{3} l h \sqrt{2gh}$. Now, it is evident that the discharge through the rectangular orifice of which B D is the height, will be equal to the difference of the discharges through the two slits, and which consequently will be

$$\tfrac{2}{3} l \sqrt{2g} \, (H\sqrt{H} - h\sqrt{h}).$$

Let us revert to the mean velocity; and first to that which we have when the slit is quite open. Let G be the point from which the fluid line animated with this velocity proceeds; if we make A G = z, it will be $\sqrt{2gz}$; being multiplied by the area of the slit $l \times H$, it must give the discharge. But we have seen that this discharge was also expressed by $\frac{2}{3} l H \sqrt{2gH}$; we shall then have $l H \sqrt{2gz} = \frac{2}{3} l H \sqrt{2gH}$; whence $z = \frac{4}{9} H$, and consequently $v = \sqrt{2g \frac{4}{9} H} = \frac{2}{3} \sqrt{2gH}$.

Thus the mean velocity will be two-thirds of the velocity of the lower line. In fact, G H, which represents the first, is, according to the above-mentioned property of the parabola, two-thirds of B C, which represents the second.

For the rectangular orifice of which B D or $H - h$ is the height, z' being the height due to its mean velocity, we should in like manner have $(H - h) l \sqrt{2gz'} = \frac{2}{3} l \sqrt{2g} (H \sqrt{H} - h \sqrt{h})$; whence $z' = \frac{4}{9} \left(\frac{H \sqrt{H} - h \sqrt{h}}{H - h} \right)^2$.

Example.—There is a prismatic basin, at the bottom of which is a rectangular orifice ·82 ft. base, and ·3937 ft. height; and during the flowing the fluid surface is constantly ·7218 ft. above the lower edge of the orifice. We then have H = ·7218; h = ·7218 − ·3937 = ·3281; thus $z' = \frac{4}{9} \left(\frac{\cdot 7218 \sqrt{\cdot 7218} - \cdot 3281 \sqrt{\cdot 3281}}{\cdot 7218 - \cdot 3281} \right)^2 = \cdot 48$ ft.; consequently the mean velocity will be $\sqrt{2g \times \cdot 48} = 5 \cdot 558$ ft.

D'Aubuisson makes the following observation, which applies more particularly to the case of heads.

During the flow through an orifice, the surface of the fluid in the reservoir, starting from certain points, is curved, and inclines towards the side in which the orifice is pierced; so that the height or vertical distance of the surface, above any part of the orifice, is greater on the up-stream side of the points where the inflection begins, than near to and touching the side. It is the first of these heights or heads which must always be introduced into the formulas of flowing. The distance between the orifice and the line where the fluid surface joins the side is very often introduced (into the formulas); from this there results an error in deficiency, in estimating the discharges which, in some cases, very rare to be sure, may extend even to a tenth of the discharge.

Such errors diminish when the head increases; and according to the experiments of MM. Poncelet and Lesbros, who have also fully explored this question, they will be insensible when the heads exceed ·4921 or 6562 ft., say 6 or 8 inches. Yet in very great orifices the depression of the surface is still perceptible; D'Aubuisson had seen it from 1½ to 2 in. against the sluice-gates of the canal of Languedoc, when the two paddle-gates were open.

If the orifice had a figure different from the rectangle, the expression of the mean velocity, and consequently of the discharge, would be more complicated; its determination would become a problem of analysis of little utility in practice, where great orifices are almost always rectangular. The solution of these problems can be seen in the Architecture Hydraulique of Belidor; and in the Hydrodynamique of Bossut. For the present we shall limit ourselves to that which concerns the circle. Designating by d the diameter, by h the head above the centre, we have for the expression of the discharge, $\pi' d^2 \sqrt{2gh} \left(1 - \frac{d^2}{128 h^2} - \frac{d^4}{3277 h^4} - \&c. \right)$; this discharge is that which corresponds to the velocity of the central line diminished in the ratio indicated by the complex factor.

The discharges, of which we have just given the expression, are theoretic discharges; for reducing them to actual discharges it is necessary to multiply them by the coefficients deduced from experiment.

These also will be furnished us by MM. Poncelet and Lesbros. We indicate them in the following Table;—

Head upon the centre.	Height of Orifices.					
	·6562 ft.	·3281 ft.	·1640 ft.	·0984 ft.	·0646 ft.	·0328 ft.
feet. ·03281						0·712
·0656				0·644	0·667	0·700
·0984				0·644	0·663	0·693
·1312			0·624	0·643	0·661	
·1640			0·625	0·643	0·660	
·1968		0·611	0·627	0·642		
·2625		0·612	0·628	0·640		
·3281		0·613	0·630	0·638		
·3937	0·592	0·614	0·631			
·4921	0·597	0·615	0·631			
·6562	0·599	0·616	0·631			
·9843	0·601	0·617				
1·6404	0·603	0·617				
3·2809	0·605					

The numbers above are the true coefficients of the contraction of the fluid vein, or the coefficients of the reduction of the theoretic discharge to the actual discharge; for theory gives no other general formula for flowing through orifices than $\frac{2}{3} l \sqrt{2g} (H \sqrt{H} - h \sqrt{h})$.

That which was established $S\sqrt{2gh}$; where $h' = \frac{1}{2}(H + h)$ applies only to particular cases, very frequent, to be sure, where h' is three or four times greater than $H - h$. In the other cases it is erroneous, and the coefficients which are adapted to it, and which it has served to determine, are erroneous also: they are the coefficients found above the transverse lines which divide the columns. (The coefficients below the lines, although determined by the aid of that formula, are accurate, coinciding with those obtained by the general formula.) Finally, in the first, $mS\sqrt{2gh'}$, the error of the coefficient m is compensated by the error of the formula, and the discharges which it gives are sensibly identical with those of the other; and as it is, besides, more simple, it is commonly employed in all cases.

Example.—What would be the discharge of a rectangular orifice ·9843 ft. wide and ·49215 ft. high, under a head of only ·16405 ft. on its upper edge? Here $H = {\cdot}16405 + {\cdot}49215 = {\cdot}6562$ ft. and $l = {\cdot}9843$ ft. The head on the centre, therefore, is ·410125 ft.; the coefficient which corresponds to this head, according to the above Table, is nearly ·603; a mean term between ·593 and ·614. Thus the discharge will be $\frac{2}{3} \times {\cdot}603 \times {\cdot}9843 \times 8{\cdot}02052\,({\cdot}6562\sqrt{{\cdot}6562} - {\cdot}16405\sqrt{{\cdot}16405}) = 1{\cdot}476$ cub. ft. The ordinary formula, with its coefficient ·592, taken from the ordinary Table, p. 1893, would have given ${\cdot}592 \times {\cdot}9843 \times {\cdot}49215 \times 8{\cdot}02052\sqrt{{\cdot}410125} = {\cdot}1473$ cub. ft.

We have a circular vertical orifice of ·0888 ft. diameter, with a head of ·0592 ft. above the centre. What will be the discharge? Here $d = {\cdot}0888$ ft., $h = {\cdot}0592$ ft.; so that the expression, p. 1907, becomes ${\cdot}012086\left(1 - \frac{1}{56{\cdot}89} - \frac{1}{647{\cdot}3}\right) = {\cdot}011863$ cub. ft. This is the theoretic discharge; and to have the actual discharge it is necessary to multiply it by the coefficient indicated in the Table. We there find 0·667 for an orifice of ·6562 ft. diameter, under a head ·0656 ft. (or of ·0592); under this same head, we then also have ·0644 for an orifice of ·0984 ft., from which we shall take 0·650 for the orifice of ·0888 ft. The actual discharge will then be $0{\cdot}65 \times {\cdot}011863 = {\cdot}00771$ cub. ft.

Hydraulic Gauge.—Darcy's gauge, the extreme accuracy of which has enabled scientific men to remove the theory of running water from the domains of speculation into those of almost absolute certainty. Darcy's gauge is a modification of an instrument invented by M. Pitot; and it will be necessary to explain the nature and working of this instrument in order to give a complete explication of the one with which M. Darcy's name has become connected. In the year 1732 M. Pitot communicated to the Academy of Science a discovery which he had made concerning the laws that regulate the motion of water in streams; he presented to that learned body the instrument by means of which the discovery had been made. His invention had enabled him to measure with considerable accuracy the velocity in any given point of the fluid fillets of which a stream is composed, and the discovery which he had made was that the velocity of water decreases as we approach the bottom or the sides of the current, a fact that is well known and well understood in the present day, but one that before Pitot's time had not been thought of, and that for a long time after was warmly disputed in consequence of a false theory then held concerning the motion of fluids.

Pitot's gauge consisted of a long wooden rod of triangular section, to one face of which two glass tubes were fixed. One of these tubes was bent horizontally at its lower extremity; the other, on the contrary, descended vertically to the level of the curved portion of the first. Pitot thought that if this instrument were exposed to the current of water it would give, by the difference of level existing between the two columns of water in the tubes, the height due to the velocity of the fluid at the point under consideration; and that it would then be easy to deduce the required velocity by means of the relation $V^2 = 2gh$, h being the difference observed. The idea was an ingenious one, and moreover it was new. Yet Pitot's instrument was looked upon by practical men with disfavour (although they continued to use it). It was considered a matter of pure speculation from which nothing practical could be derived. And to obtain the mean velocity of a stream of water recourse was always had, either to vertical floats equal in length to the depth of the portion of water whose mean velocity it was required to find, or to some other instrument more or less complicated and needing the assistance of a time-marker. The reason of this lies in the fact that Pitot's instrument, wonderful as it was, was nevertheless in some degree founded in error. Reduced to its simplest theoretical form it might be constructed of a single glass tube horizontally bent at its extremity: the water entering through the horizontal portion which is exposed to the current, holds itself in equilibrium in the vertical tube at a height above the surface of the current equal to $h = \frac{V^2}{2g}$, V being the velocity of the fluid fillet under consideration. When circumstances enable us to measure h and g exactly, we may deduce V from this height with sufficient precision. But usually the chopping of the water against the outer surface of the tube and its supports does not allow us to compare the level of the water in the tube with that of the surface of the stream troubled by the presence of the instrument, and even this surface of the stream is not easily measured on account of the undulations which cover it. It was to avoid this difficulty, which Pitot no doubt discovered by experience, that he added the second tube, the lower end of which was beneath the surface of the water.

Pitot thought that the level of the water in the straight tube must be equal to that of the surface of the stream, and that in this way the difference of level or h, the height due to the velocity, might be readily obtained. Here lay the first error. When a straight tube is placed in a stream of water, the water in the tube stands below the superficies of the stream by a quantity in a constant ratio with the square of the velocity of the fluid fillet passing beneath its lower orifice. Thus the difference h between the levels of the water in the tubes represents a quantity greater than the height due to the actual velocity of the fluid fillet in question. Hence arose an error which rendered Pitot's conclusions inexact. Besides this, the oscillations were very strong in tubes so arranged, especially as the orifices had the same diameter as the tubes; nay more, it was even deemed necessary to make these orifices funnel-shaped. Thus we see how it was that Pitot's tube could be of no practical use. In the first place its construction was founded upon an erroneous principle, and in the second place the oscillations which took place in the tubes rendered it impossible to estimate truly, especially in the case of feeble velocities, the required difference of level.

We will now consider the modifications which Darcy has made in Pitot's instrument, modifications that have rendered it exact in its results and easy of application. Many careful experiments showed him that if, in a stream of water, in any point of the fluid having a velocity V, we place a vertical tube bent horizontally at its lower extremity, and having its orifice placed first against the stream, then in the direction of this latter, and lastly rectangularly to its direction, there exists a constant relation between the theoretical height $\frac{V^2}{2g}$ due to the velocity of the fillet under consideration, and the quantities h', h'', h'''; h' representing in the first case the height by which the level rises in the vertical branch above the surface of the stream; h'' and h''' the quantities by which the level sinks below the surface of the same stream on the other two hypotheses. In this way, like General Anstruther, he changes the erroneous value given to g. We may therefore state;—

$$\frac{V^2}{2g} = m\,h', \qquad \frac{V^2}{2g} = m\,h'', \qquad \frac{V^2}{2g} = m\,h''',$$

combining either the first and second, or the first and third of these equations;—

$$V = \sqrt{\frac{m\,m'}{m + m'}}\,\sqrt{2g\,(h' + h'')} = \mu\,\sqrt{2g\,(h' + h'')};$$

$$V = \sqrt{\frac{m\,m''}{m + m''}}\,\sqrt{2g\,(h' + h''')} = \mu'\,\sqrt{2g\,(h' + h''')}.$$

Seeking in the tables the velocities corresponding to the heights $h' + h''$, $h' + h'''$, we find velocities V′ and V″; the above equations become therefore $V = \mu\,V'$ and $V = \mu'\,V''$. It will be seen from this that it is not necessary to know the level of the surface of the water in which the instrument is placed in order to determine the required velocity. And it must be remarked further that the oscillations in the tubes have been almost nullified by giving the orifices a diameter of only 1½ millimètre, whilst that of the tubes is 1 centimètre. But as these oscillations, however feeble they might be, would still cause the observer some trouble, a cock has been added by means of which the lower orifices of the tubes may be closed simultaneously. These orifices being closed, all communication with the stream is cut off, and the difference may be read upon the tubes and the velocity deduced with perfect ease and precision.

Darcy's gauge possesses another important modification. Most hydrometrical instruments have the grave defect of altering the velocity which they are designed to measure, by the disturbance which they cause in the fluid mass. It was necessary therefore to diminish the size of the gauge, and to remove as far as possible from the divided scale upon which the tubes are fixed, the orifices through which the fluid fillet enters whose velocity it is required to determine. To obtain this double result the scale to which the tubes are fixed is made as thin as possible and bevelled, and copper tubes of a very small diameter affixed below to the glass tubes, the ajutages being placed at the extremity of these copper tubes. Here another question arises; How are we to measure the velocities at the surface or even of the whole liquid mass equal in depth to the length of the copper tubes through which the water cannot be seen? This result has been obtained by the following means: the two glass tubes communicate with each other in their upper portion by means of a copper tube which is hermetically adjusted to them; upon this copper tube a cock is placed which, according as it is open or shut, puts the tubes in communication with the atmosphere, or cuts off this communication. Above this cock is a little mouth-piece, by means of which an imperfect vacuum is produced by suction; the water ascends in the glass tubes to the height desired, and is kept in that position by closing the cock which cuts off the communication with the atmosphere. The upper cock offers the additional advantage of enabling the operator to determine, with an instrument of a height much less than the depth of the stream, the velocity of the latter at a given depth. To effect this, he has merely to lower the instrument 1, 2, or 3 mètres into the water by means of an iron rod, to which it is fixed in such a way as to preserve its mobility about a vertical axis, and the orifice of the horizontal portion of Pitot's tube is kept directed against the stream by means of a kind of rudder.

In the former case the instrument acts under dilated air; in the latter under more or less compressed air. But it is evident that in both cases the differences of level between the tubes are the same as if the operation were performed under the influence of atmospheric pressure.

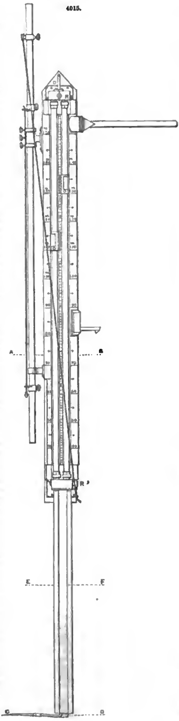
Fig. 4015 represents the most approved form of Darcy's gauge. The vertical glass tubes are $1^{m}\cdot25$ in length; the two small copper tubes placed on the lower portion are enclosed in a kind of box, also of copper, Figs. 4015 and 4018, $0^{m}\cdot77$ long, $0^{m}\cdot06$ broad, and only $0^{m}\cdot011$ thick; this box ends on both sides in a sharp angle for the purpose of lessening as much as possible the shock of the water, a result which is perfectly obtained, as the instrument when placed in the water causes no appreciable disturbance.

The measurement of the velocities in a given point of the section of a stream is effected in the following manner. Above the stream, at the point at which the experiments are to be made, a slight temporary bridge is constructed, and a stoutish rail fixed for the purpose of supporting the weight of the instrument. On the back of the gauge-tube is an arrangement by means of which, with the aid of a thumb-screw, it may be fixed at the height necessary to bring the ends of the tubes to the required point. An iron handle enables the assistant upon the bridge to hold the tube in an exactly vertical position indicated by a plumb-line.

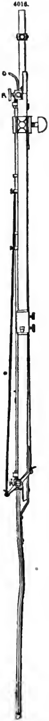
The instrument being thus placed, and the upper and lower cocks closed, the operator sucks out by the mouth-piece O, Figs. 4015, 4016, a portion of the air contained in the tubes, so as to make the water ascend to a height convenient for reading, then he closes the upper cock R. The difference of level between the two columns of water in the instrument then establishes itself at once; but both are subject to continual oscillations. When the operator wishes to read the difference, he closes, by means of a string, the lower cock R′; the columns of water then become motionless, and their respective heights may be read without the slightest difficulty.

We conclude these remarks with an example of the method of using this instrument, taken from M. Darcy's work on Hydraulics. It must be remembered that every possible precaution had been taken to ensure a uniform flow of water in the course selected for experiment. A breadth of 2 mètres was preserved throughout; the sides were carefully boarded, and the bottom rendered smooth and hard, and of a uniform descent. The depth of the stream was carefully measured throughout in the following way. Upon each of the cross-pieces of timber which supported the boarded sides of the water-course were placed three nails, one in the middle, and one within $0^{m}\cdot33$ of each side. The height of each of these nails above the bottom of the water-course was then measured, as well as their height above the surface of the water; the difference of these heights evidently gave the depth of the stream upon the vertical line passing through each of the three nails. This operation, which required great care, was performed by means of a slide-rule, Fig. 4020, terminating in a sharp iron edge. The operator rested the slide upon the cross-piece over the stream, and let the rule down till the end touched the surface of the water. The maximum velocity was measured both by means of the gauge and by means of floats. The use of these floats required great precautions; sometimes simple wafers were used, sometimes small pieces of wood or cork, weighted with lead, so as to skim along the surface of the water, Figs. 4021, 4022. By means of a time-marker indicating fifths of a second, the time occupied by each float in traversing a space of 40 or 50 mètres was exactly determined. The operation was several times repeated; and only those in which the float had followed perfectly the axis of the current were taken into account at all; even then the mean of five or six results, at least, were taken. With respect to the results obtained by the gauge, the difference of height in the two

4015.



4016.



Elevation of the right side.

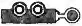
columns of water being constantly variable, care was taken in reading to seize the moments of the *maxima* and *minima*. Two or three *maxima*, and as many *minima* were noted, and the mean of all the operations taken.

EXAMPLE.

Heights		Differences.	Observations.
In the tube against stream.	In the tube with stream.		
mètres.	mètres.	mètres.	
0·953	0·822	0·131	Maximum.
0·948	0·830	0·118	Minimum.
0·950	0·822	0·128	Maximum.
0·945	0·825	0·120	Minimum.
0·933	0·803	0·130	Maximum.
0·925	0·808	0·117	Minimum.
	Mean ..	.. 0·124	

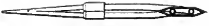
Whence $V = \mu \sqrt{2g \times 0^{m}\cdot 124}$. Our old friend, *g*, plays a great part here, see GUNNERY.

4017.



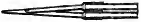
Section through A B.

4018.



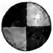
Section through E F.

4019.



Section through C D.

4021.

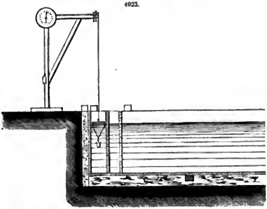


4022.

Elevation.

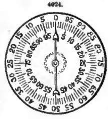
Cork float weighted with lead. Plan.

4023.

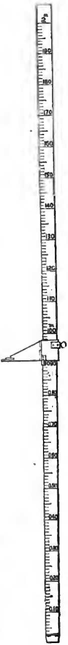


The dial-float, Figs. 4023, 4024, was used by M. Darcy to secure an unvarying level in the water-course in which his experiments were made. This float, Fig. 4023, consisted of a zinc floating piece weighted with lead; to the upper portion was fixed a piece of ribbon which passed over two pulleys, and which was kept tight by means of a weight attached to its other extremity. The axis of one of the pulleys formed the centre of a dial, Fig. 4024, $0^{m}\cdot 32$ in diameter; a small steel index marked upon this dial the slightest rotary motion of the pulleys, and consequently the slightest variations of level. The float was enclosed on all sides by a vertical wooden casing, forming a kind

4024.



4020.



Rule for measuring the depth of water.

of well; the water contained in this well was in communication with the surrounding water only at the bottom by means of small holes in the casing. The object of this arrangement was to prevent the irregular motion of the surface from disturbing the float. The assistant whose duty it was to attend to the water-gates, was able, by glancing to this dial, to keep the level of the water constant within 1 or 2 centimètres.

See Archimedian Screw. Barker's Mill. Barometer. Barrage. Boiler. Canal. Damming. Displacement. Float Water-wheels. Gunnery, p. 1759. Hydraulic Machines, *Varieties of*. Overshot Water-wheels. Pipes. Pumps and Pumping Engines. Reservoirs. Rivers. Turbine Water-wheels. Undershot Water-wheels. Weirs.

HYDRAULIC MACHINES, Varieties of. Fr., *Machines hydrauliques*; Ger., *Wassermaschinem.*

Hydraulic Motors.—It is an incontestable fact that hydraulic motors render great and frequent service to industry: for though they are not adequate to every emergency, as steam-engines are, they possess the no small advantage of requiring only the first outlay necessary to establish them, the redemption of which with the interest accruing thereto, added to the expense of repairing, which is very small, constitute the only general costs of the motive power of a mill driven by water.

The disadvantage inherent to hydraulic motors lies in the variations of level and volume to which a fall of water is liable; whence it follows that the power employed through its medium is not constant throughout the year; in some seasons it may be insufficient, in others greater than the requirements of the mill demand. But, as the productive power of a mill must generally be regular and constant, the regulating the power of water-courses becomes a matter of great importance. Unhappily the causes of the variations of level and volume in a stream of water are such that, in most cases, they can be only imperfectly counteracted, for the remedy consists simply in establishing large reservoirs in which the water may accumulate during the rainy seasons, and from which it may be drawn in nearly constant quantities, so that the uniform and constant discharge a minute, for example, multiplied by the number of minutes in the year, would give the total volume furnished in that space of time by the dam in question. This exactness, however, cannot be attained; but we have not yet succeeded in establishing a rational state of things. The periodic and frequent inundations which take place show how little care we take to profit as much as possible by a motive power which nature offers us almost for nothing. A few barrage-reservoirs have indeed been constructed here and there; but their number is greatly inadequate to the requirements of industry, and their construction has not yet tempted private speculation and energy. If the enormous sums of money which have been sent out of the country to be swallowed up in bubble undertakings had been expended in improving our water-course, navigation, agriculture, and manufactures of all kinds would have received immense benefits.

Our examination of motors, or more accurately, hydraulic *receptacles*, will comprise the three following categories:—1, *ordinary* hydraulic wheels with a horizontal axle, utilizing either the weight of the water or the velocity due to its fall; 2, *turbines* with a vertical and with a horizontal axis, utilizing the velocity and consequently the *vis viva* of the water; 3, *reciprocatory engines*, or motors worked by water pressure, in which the water acts upon a piston having an alternating rectilinear motion. We purpose here to show the actual state of progress realized in the construction of this widely-known class of motors.

Preliminary General Notions.—The *gross* power of a water-mill is found by multiplying the weight P of the volume furnished by the stream a second, by the height H of the fall. Dividing this product by 75 kilogrammètres (the work corresponding to 1 horse-power) we get the gross power F expressed in horse-power,

$$F = \frac{P\,H}{75}. \qquad [1]$$

The *effective* power of the mill depends solely upon the kind of motor adopted; it is the product of the gross power by the useful effect K of the motor;—

$$\text{Effective power } F_e = K\,\frac{P\,H}{75}. \qquad [2]$$

It is therefore necessary in each particular case to choose the motor best adapted to the conditions of fall and volume in the stream to be used. The rules for the establishing of water-wheels are the object of a special study, and would be out of place here; but we will show the application of them in the critical examination which we purpose to make.

Common Water-wheels with a Horizontal Axle.—These comprise three principal classes;—

Wheels which receive the water on the top, or in a point situate between the summit and the horizontal plane passing through the axis. These are called *overshot wheels.*

Wheels which receive the water between their centre and the bottom. These are called *breast-wheels.*

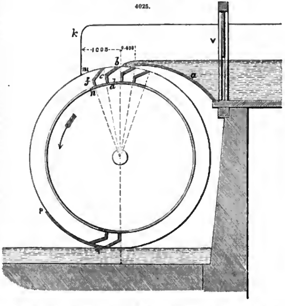
Wheels which receive the water at the bottom, and upon which the water arrives with a velocity due to a height nearly equal to that of the fall. These are called *undershot wheels.*

Overshot Wheels.—These wheels are applicable to high falls, that is, comprised between 3 and 12 mètres; above this limit their construction becomes difficult and costly.

When the stream has only a very small discharge, not exceeding 300 litres a second, the canal which brings the water to the wheel is brought out to the crown of the wheel by a kind of trough, the bottom of which is cylindrical, *a*, nearly concentric with the wheel itself, Fig. 4025. This bottom, which is usually of wood, terminates in a horizontal plank forming the overfall, which is placed at about $0^{m}\cdot400$ short of the vertical line drawn through the axis of the wheel. The water flows over in a sheet, the thickness of which must not exceed $0^{m}\cdot150$ to $0^{m}\cdot200$ at the most.

We see at once that this system of wheel does not admit of variations in the level of the upper lade, for the smallest variations in this level would be great relatively to the thickness of the sheet of water on the overfall, and would cause considerable variation in the expenditure of water and consequently in the force of the wheel and its velocity; and that the wheel must never dip into the tail-water, because the immersion of the buckets would prevent the efflux of the water and lessen the work of the wheel. Therefore, if the level of the tail or back water varies, the bottom of the wheel must be fixed at the highest level.

4025.



Overshot wheels of this kind, that is, *without a head of water*, are only suitable to streams that are nearly constant in their flow, and to mills that offer a regular resistance, such as corn and spinning mills. These wheels may be constructed wholly of wood, of wood and iron, or wholly of iron (cast iron, wrought iron, and plate iron). Two cheeks *k* placed on each side of the trough enable several buckets to be filled every time the wheel is started. These cheeks should extend about 1 mètre beyond the vertical passing through the axis of the wheel. The sluice V fixed at the head of the trough is only for the purpose of stopping the wheel; when the wheel is going, the sluice is wholly raised, and consequently does not regulate the discharge.

When the buckets are of wood, which is usually the case, they are composed of two pieces, *b c* and *c d*, one of which is fixed in the direction of the radius, and the other in the direction of the *relative* velocity of the inflow of the water into the wheel. The direction of this relative velocity is found by comparing the *absolute* velocity with which the water arrives upon the wheel, and an equal velocity directly opposed to the *linear* or *tangential* velocity from a point in the outer circumference of the wheel. Usually the distance of two consecutive buckets apart is equal to the depth *m n*; this depth should not exceed $0^m\cdot400$. The buckets are enclosed between rims or shroudings fixed to the arms. If the breadth of the wheel exceed $1^m\cdot50$, one or two intermediate rims are required, supported by a system of arms similar to those for the outer rims.

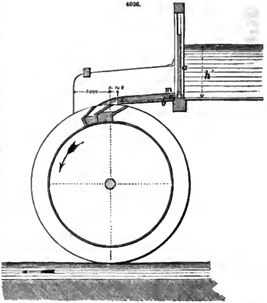
The rotatory motion of the wheel impresses upon the surface of the water in each bucket the form of a portion of a cylindrical surface, the generatrices of which are horizontal, and the straight section of which is an arc of a circle, whose radius is expressed by $\frac{g}{\omega^2}$, ω representing the angular velocity of the wheel. The water has a tendency to leave the wheel before the lowest point is reached; the consequence of this is a loss of work great in proportion to the height of the point *p*, where the anticipated discharge begins, above the level of the lower mill-race. This loss may be avoided by fixing a circular apron *p q* around the lower portion of the wheel from the point *p*.

Overshot waterfalls, without a head of water, ought not to receive more than 100 litres of water a second to the mètre of breadth. Their effective work varies from 0·75 to 0·85 of the gross work. If the level of the upper mill-race and the volume of water are variable, the wheel cannot be fed by means of an overfall; arrangements must indeed be made by which the volume of water expended by the wheel may be varied, according to circumstances, without changing the velocity with which the water flows upon the wheel. These conditions are satisfied by constructing a vertical sluice *a* with a head of water *h'*, Fig. 4026, so that the distance *m n* from the bottom of the sluice to the floor of the pen-trough may in all cases be much less than the height *h'* of the head of water. A wheel-race *b c*, inclined to about $\frac{1}{10}$, brings the water upon the wheel; this race is provided with two side cheeks *d*, which extend about 1 mètre beyond the vertical line, passing through the axis of the wheel. The construction of this system of wheel differs in nothing from that described above. As we have already stated, the wheel must not dip into the back-water, and the anticipated discharge of the water may be prevented by the cylindrical apron shown in Fig. 4026.

The height h' of the head of water depends upon the total height H of the fall, and on the variations of level in the upper mill-race. It is not possible to fix absolute figures with respect to this; yet the values adopted should approximate to the following numbers;—

Values of H.	Values of h'.
3 to 4 mètres.	0·60 mètre.
4 to 6 "	0·70 "
6 to 7 "	0·80 "
7 to 8 "	0·90 "

4026.

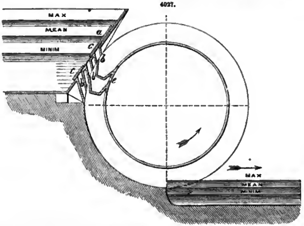


In this system of wheel, as in the preceding, the linear velocity measured on the outer circumference of the wheel should be about equal to that with which the water flows upon the wheel.

Wheels with a head of water may receive 120 litres and even more to the mètre of breadth a second. Their effective work is a little less than that of wheels without a head of water, and may be reckoned, as a mean, 0·75.

When the level of the lower mill-race varies a little (from $0^m{\cdot}10$ to $0^m{\cdot}15$ at the most), and the level of the upper race and the volume of water vary greatly, the most suitable kind of wheel is that represented in a general way by Fig. 4027. The upper mill-race terminates in a cast-iron pen-trough a, the inclined front of which is provided with a number of ajutages b, b, b. These may be opened or shut by two rectangular sluices c, c, each worked by its own mechanism. The buckets have the form shown in the figure, and the sole is provided with ventilators. One or more of the orifices is opened, according to the volume of water to be expended, and the position of the level in the upper mill-race. The water is applied to this wheel at a point situate between the summit and the centre; it is known as the *Wesserling* wheel, because the most remarkable specimen of this kind is to be found at Wesserling, on the Rhine.

4027.



The diameter of these wheels is usually determined by taking it equal to the height of the fall increased by 1 mètre. There is nothing absolute about this rule; it is subordinate to the condition of obtaining on the ready introduction of water into the wheel, and a convenient form for the buckets. As this wheel moves in the direction of the water in the lower race, it may be submerged to a certain degree, $0^{m}\cdot10$ to $0^{m}\cdot12$. It may receive 240 litres a second to the mètre of breadth, and its effective work is from 0·65 to 0·72.

The shaft of a bucket-wheel may be of wrought iron, cast iron, or wood; the arms may be of the same materials, but they are usually fixed in cast-iron sockets bolted to the shaft. When the buckets are of plate iron, they are usually curved according to a cylindrical surface.

As the Paris Exhibition contained no specimen of a trough-bucket wheel, we have introduced here the drawings of one constructed wholly of iron. Figs. 4028 to 4035 represent this specimen. The diameter of this wheel is 10 mètres, and its breadth 1 mètre; it weighs, including its shaft and gearing, about 18,000 kilogrammes. The wheel, which is fixed upon a cast-iron shaft, carries 120 buckets of plate iron; the arms are of I iron. Against one of its shroudings, and firmly bolted to the arms, is a toothed wheel, composed of twelve segments. A bracing of oblique wrought-iron ties prevents the transverse warping of the wheel. The shrouding and the buckets are of plate iron; these buckets are riveted to the shrouding by means of angle-iron.

Breast-wheels.—Under this name are included those wheels which are enclosed in a circular breast or arc, and which receive the water at a point situate between their centre and their lowest part.

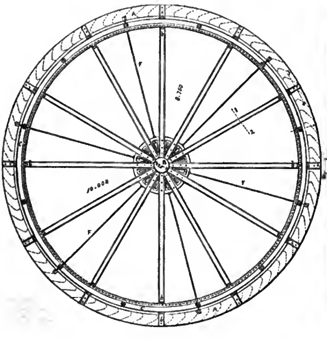
Let us denote by H the whole fall made use of by the wheel, that is, the difference of the height of the levels in the upper and lower mill-race; by h the fall utilized by the wheel, that is, the height of the point at which the water is applied to the wheel above the level of the lower race; by V the velocity of the water on its arrival upon the wheel; by v the velocity of a point of the periphery of the wheel; and by P the weight of the volume of water expended a second. Theory readily leads to the expression of the useful effect or work T of the wheel as a function of these quantities. We have

$$T = Ph + \frac{P}{g}(V \cos.\ Vv - v)\,v\,; \qquad [3]$$

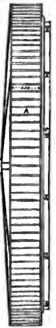
so that the fall utilized by the wheel is expressed by $h + \frac{v}{g}(V \cos.\ Vv - v)$, and its duty

$$K = \frac{h + \frac{v}{g}(V \cos.\ Vv - v)}{H}, \text{ of which the maximum is } v = \frac{V \cos.\ Vv}{2}.$$

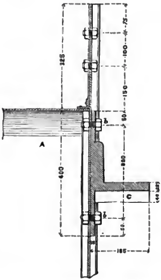
4028.



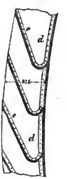
4029.



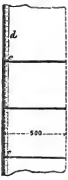
4030.



4031.



4032.



4033.

4034.

4035.

The duty increases as V decreases, that is, the height of the portion of the fall taken as the generating weight of the velocity must be reduced as much as possible. Hence we have, for breast-wheels, the first arrangement, which consists in supplying the wheel by means of a sluice that allows the water to flow upon the wheel from an everfall. This first class of breast-wheels are called *slow* wheels.

But this condition of flowing from a weir or everfall is often incompatible, either with the volume of water to be expended, or with the variations of level in the upper mill-race; hence the necessity of a sluice allowing the water to flow beneath it, that is, with a head of water. In this case the velocity V, and consequently that *v* of the wheel, are greater than in the preceding case. We thus obtain what are known as *mixed* or *impulse* breast-wheels.

4036.

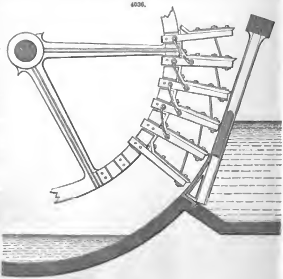


Fig. 4036 represents in elevation a *slow* with straight floats, built by the Messrs. Féray and Co. of Essonne (France). The driving sluice is inclined so as to be placed as near as possible to the wheel. This sluice slides between two cast-iron supports fixed in the side walls, and rests against a fixed cast-iron apron called a *col-de-cygne*, to which a circular stone arc, covered with a layer of cement, forms a continuation; this arc must be constructed with care, so that the play to be left between the wheel and the arc may be reduced to within a few millimètres.

The thickness of the sheet of water received by a slow wheel from an overfall, should be at the most $0^m{\cdot}35$ to $0^m{\cdot}40$; with respect to the percentage of work and the ready introduction of the water into the wheel, the best thickness is $0^m{\cdot}25$. The upper edge of the sluice should be rounded on the side of the water; often the sluice is provided on this side with a strip of sheet iron curved from left to right to guide the lower fillets before they reach the sluice, and consequently lessen the contraction.

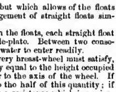
Instead of satisfying the relation $v = \frac{V \cos. V v}{2}$, most builders fulfil the condition $v = V \cos. V v$, which is less favourable with respect to the percentage of work, but which allows of the floats being fixed in the direction of the radii of the wheel; this arrangement of straight floats simplifies the construction of wheels.

To utilize, in part at least, the relative velocity of the water upon the floats, each straight float is continued by a counter-float inclined upon the float and the sole-plate. Between two consecutive floats is a ventilating aperture in the sole-plate to enable the water to enter readily.

An absolute condition from a theoretical point of view, which every breast-wheel must satisfy, is to be immersed in the water of the tail-race by a quantity exactly equal to the height occupied by the water in the floats that have reached the line perpendicular to the axis of the wheel. If the wheel does not dip deeply enough, there is a loss of fall equal to the half of this quantity; if the wheel dips too deeply, it meets in the water of the tail-race with a resistance which is equivalent to a loss of fall. Great care is therefore necessary in all cases to fix the position of the wheel in accordance with the variations of the volume which it is to expend, and the level of the water in the tail-race.

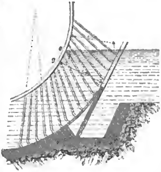
A Belgian millwright, M. Delnest of Mons, exhibited in the Paris Exhibition of 1867, a small model of a wheel of his own invention, called a *helicoidal-float wheel.* Fig. 4037 is a kind of perspective of this wheel. The shaft, centre boss, and arms, possess no peculiarity: the sole-plate is continuous and is not provided with ventilators. According to M. Delnest, the air issues naturally in virtue of the form of the floats, which, instead of being placed according to the generatrices of the cylinder of the shrouding, are formed of two parts inclined in opposite directions upon these generatrices. The form of the floats certainly causes no perturbations in the inflow of water; the absence of ventilators, which M. Delnest seems to have suppressed for the purpose of increasing the capacity of his wheel with respect to that of a common breast-wheel of the same dimensions, prevents the floats from discharging their water readily. The inclination of the floats upon the generatrices of the sole-plate throws the tail-water against the sides of the mill-race, which it tends to wear away. We think therefore that this kind of wheel is destined to remain in its condition of a model, its duty being necessarily inferior to that of a good breast-wheel with straight floats, erected conformably to theory, and to arrangements sanctioned by long experience.

4037.



A M. Sagebien, who is an engineer at Amiens, taking into consideration the fact that, from a theoretical point of view, the two causes of a loss of work in a water-wheel are the loss of *vis viva* corresponding to the relative velocity of the water in the floats and the loss of *vis viva* due to the velocity with which the water leaves the wheel, was induced to consider a system of wheel in which the water flows upon the wheel with a very feeble velocity, little above that which it possesses in the mill-lead; so that the sheet of water which flows upon the wheel is of a thickness nearly equal to the depth of the water in the lead. The wheel itself moves very slowly; the velocity of a point in its periphery is usually between $0^m{\cdot}60$ and $0^m{\cdot}70$ a second (see Fig. 4038). The water does not *fall* upon the wheel as in the case of breast-wheels; it moves horizontally, and the float-boards of Sagebien's wheel must fill themselves in the manner of a pipe open at both ends when dipped slowly into the water. This kind of wheel is therefore something of a water-meter.

4038.

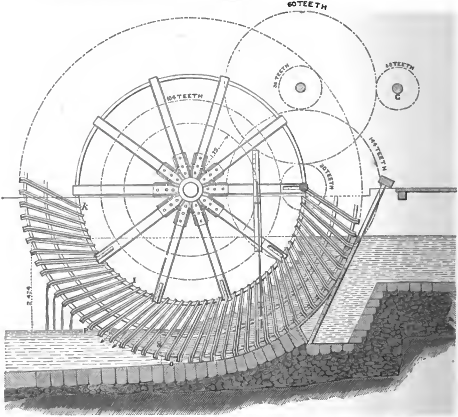


The theoretical conditions which Sagebien's wheel must fulfil, require the floats to have a direction very different from that adopted in common breast-wheels; these floats, as shown in Fig. 4038, are all tangent to a circumference concentric with the wheel.

The driving sluice is opened by being lowered; a little above this sluice there is a trench to catch the stones brought down by the water. It must be remarked here that the extremity or first element of the float-boards has the direction of the radius; this arrangement, contrary to the principles upon which this kind of wheel rests, is designed to prevent the floats being broken in the event of any hard body getting between them and the floor of the race.

Fig. 4039, one of Sagebien's wheels constructed wholly of iron, with the exception of the floats, which are of wood. The low velocity possessed by this wheel requires a very large diameter (8 to 10 mètres, and even more) and very deep floats. This wheel makes from 1 to 1½ revolutions a minute. We see from Fig. 4039 that the driving shaft of the mill makes about $1 \cdot 5 \times \frac{104 \text{ teeth}}{30} \times \frac{144}{36} \times \frac{160}{40} = 83$ revolutions a minute, in round numbers. It will be seen that Sagebien's wheel requires great complication in the transmission of the movement. In Fig. 4039 the shaft and centre bosses are of iron, the arms of I iron, the shroudings of plate iron, and the supports of angle-iron riveted upon the shroudings.

4039.



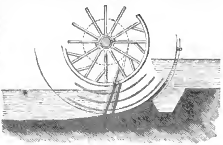
The great diameter required by this system is necessary to avoid too great a resistance offered by the tail-water to the discharge of the water in the floats.

M. Sagebien, in order to study the action of the water in his wheel, put the course in communication with a small reservoir, in which he placed a float with a vertical stem. By doing this in several parts of the course in succession, he was enabled to ascertain that the quantity of water enclosed between two consecutive float-boards varies proportionally to the velocity of the wheel; so that, abstracting the quantity lost through the play of the wheel, the volume of water expended by the wheel in a given time is equal to the volume generated by a float in the same time. In this, however, Sagebien's wheel differs in no wise from a common breast-wheel.

M. Sagebien exhibited in the 1867 Exhibition three plans of his system of wheel, which he calls the *siphon-wheel*, or "wheel with immersed floats and a constant level." Fig. 4040 represents roughly one of the three types exhibited. It applies to a wheel of a very large diameter (10 to 12 mètres), the floats of which dip at least 2 mètres in the tail-water. Such a wheel may receive at least 1000 litres a second to the mètre of breadth. We ought to remark here that the water expended by a Sagebien wheel cannot be calculated by applying to the sluice-gate the formula relative to weirs; for the calculation thus made would give a discharge much greater than the true one.

As this wheel turns very slowly, it will be seen that the play which must necessarily exist between the floats and the course has a very sensible influence upon the volume of water expended, which is consequently greater than the capacity of the float-boards. These float-boards are very close together and very numerous. The low velocity of this kind of wheel gives occasion to considerable strain upon the floats and upon the teeth of the gearing which transmits immediately the motion from the wheel.

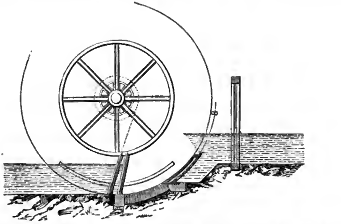
4040.



In Fig. 4040 the shaft is of iron; upon this shaft are fixed several cast-iron centre bosses in two pieces, each half of which holds six arms. The twelve arms of each centre boss are fixed to a shrouding of plate iron, upon which the supports are riveted; these supports are simply angle-irons, to which the wooden floats are bolted. They are bound together by three iron bands. The sluice-gate, instead of being straight, is curved concentrically with the wheel. This arrangement is good in principle, because it enables the sluice-gate to be placed quite close to the wheel; but it is very difficult to get a curved sluice of so great a size to work well.

Fig. 4041 represents a wheel of the same kind, but of smaller dimensions. The mode of construction is that first adopted by M. Sagebien; it consists of cast-iron centre boss in one piece, in which the arms of I iron are set. The supports are of angle-iron, and they are riveted upon the shroudings, which are of plate iron; the supports are bound together by an iron band. We prefer the construction of Fig. 4040, as being more simple; this is its only merit, for rigidity not being the dominant quality of such large wheels, their greater number of parts increases the danger of *dislocations*.

4041.



A little above the sluice-gate, which is curved, Fig. 4041, and concentric with the wheel, is a *guard-sluice*, which is always open, except when repairs are needed in the driving sluice. The arrangement of the pit at the back of the sluice-gate is bad, for the stones which accumulate in it are likely to interfere with the descent of the gate; the arrangement in Fig. 4040 is far preferable.

The third type exhibited, Fig. 4042, differs from the other two only in the form of the float-boards, which are curved instead of being straight. It appears to us that no theoretical reason can be seriously given to justify this form; but the difficulty of construction, the danger of breakage in case the end of the floats should touch the course, and the greater facility with which the floats lift the tail-water, each one being a kind of spoon, lead us to condemn, from a theoretical point of view, this form as utterly vicious. We will sum up our opinions of Sagebien's wheels by saying, they are very expensive to build, fix, and keep in repair;

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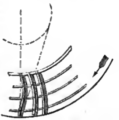

the gearing necessary to transmit the motion costs as much as the wheel itself; it requires a long time to start them; they do not last long unless they are used for mills offering a perfectly regular resistance, and their various parts require to be frequently screwed up, which renders them unfit for mills that work uninterruptedly. M. Sagebien has himself confirmed our opinions as far as the too low velocity of his wheels is concerned, by exhibiting the machinery of the water-works established by him, for the supply of Paris, at Thilbardon, on the Marne. The pumps are worked by one of his wheels; but the velocity of the wheel is so small that it was found necessary to have a special shaft to drive the pumps, revolving about three times faster than that of the wheel, with which it is connected by a pair of spur-gear. The defect which we pointed out has therefore produced another; for gearing should be avoided as much as possible in water-works designed for permanent service, and in which the chance of breakage and consequent stoppage should be reduced as much as possible.

We ought to add to the foregoing that Sagebien's wheel is not suitable to water-courses that vary in level and volume; the variations of level in the tail-race can only be such as to keep this level about the same as that of the water in the floats that have reached the line perpendicular to the axis of the wheel; in other words, the variations of level in the tail-race must be proportional to those of the volume furnished by the stream. If the volume of water is variable, Sagebien's wheel will be too *heavy* when the stream is low, and will *work with difficulty* in times of floods. Besides, circumstances will occur when the level of the tail-race will be higher than the level of the water in the floats that have reached the line perpendicular to the axis of the wheel, Fig. 4043; hence a considerable resistance from the tail-water, and a consequent loss of work.

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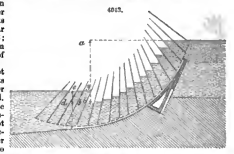

Undershot Wheels. — In undershot wheels the water arrives upon the floats with a velocity due to a head of water nearly equal to the height of the fall. When the floats are straight and radiate from the centre, the wheel is most imperfect, and its theoretical duty cannot exceed 50 per cent.; so that the practical duty does not exceed 35 or 40 per cent. of the gross work; and even to obtain this result, the wheel must be enclosed, on its lower portion, in a circular course equal in extent to the space of three consecutive floats, in order that there may not be in any case *direct* communication between the upper and lower races; care must be taken also to incline the sluice-gate from the wheel, and to place it as near to the latter as possible.

The duty of these undershot wheels with straight floats may be improved by utilizing the velocity possessed by the water on leaving them. This is effected by making the floor of the course, immediately beyond the plumb-line of the wheel, a little lower than the natural level; in this way 0·35 or 0·45, or the real height of fall, may be gained. The way of doing this is to give, for a distance of 2 mètres, an inclination to that portion of the race which immediately follows the circular course sufficient to enable the water to flow over it with a velocity equal to that of the wheel; from this part the race slopes about $\frac{1}{10}$ down to the natural bed of the stream.

The depth of the floats should be equal to at least three times the opening of the sluice-gate; but this rule is not always sufficient; it is better to lay down the condition that the depth of the floats must be such as to keep them above the highest level of the tail-water.

General Poncelet has made float-wheels the object of his special study, for the purpose of ascertaining the best arrangement for utilizing the impulsive force of the water. The result of his researches was the construction of an undershot wheel in which the floats are curved, so that their first element upon the periphery of the wheel has the direction of the relative velocity of the water with respect to the wheel. The consequence of this arrangement is that the water enters the wheel without shock, and ascends in it to a height nearly equal to that due to its relative velocity; the water then escapes from the wheel with an absolute velocity that may be much below that of the wheel, if the form of the floats has been properly studied. In order that the fluid veins of the sheet of water which arrives upon the wheel may all be placed in the same theoretical conditions, regard being had to the form adopted for the floats, M. Poncelet establishes between the sluice-gate and the bottom of the wheel a curved course, the longitudinal profile of which is an arc of an involute of a circle.

The Paris Exhibition of 1867 contained no remarkable specimens of undershot wheels with straight floats, nor of Poncelet's wheel. Figs. 4044 to 4052 represent one of these latter, wholly of iron, which has been erected at the manufactory of Guérigny (France). The shaft of this wheel is of iron; upon this shaft are fixed three cast-iron centre bosses, in each of which are set eight flat iron arms firmly bolted to it. These arms are riveted to segments of the plate-iron shroudings held together by riveted joint-plates. The floats are of sheet iron, and have been curved upon a model; they are fixed upon angle-iron curved upon the same model, and riveted to the shroudings. Each set of arms are broad in the middle, with flat iron braces bolted to the arms; and the three shroudings are held by round tie-bars. This mode of construction is at once light and strong. The duty of Poncelet's wheels varies from 0·50 to 0·65.

In terminating our review of common water-wheels we ought to call attention to the float-wheels of M. Colladon, a Swiss engineer. These are wheels with straight floats, and are designed to utilize the power of streams very variable in level, and offering only a very low fall. These wheels utilize the impulsive force of the water, and to prevent their being submerged in flood time, M. Colladon places their axes upon movable supports, which renders them capable of being raised or lowered at pleasure. It is a very primitive kind of wheel, having a duty inferior to that of common

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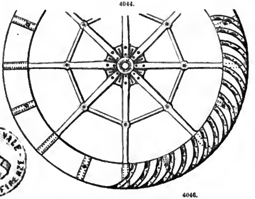

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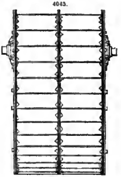

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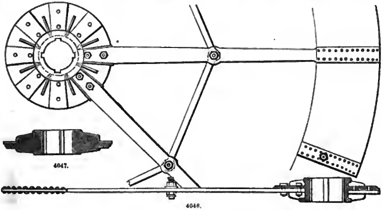

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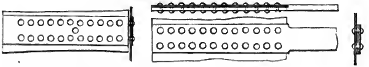

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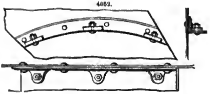

undershot wheels with straight floats, when well established. It is not suitable for wheels of great power, on account of the complication which is the consequence of the movability of the axis and the little rigidity which results from it.

Turbines.—Under the name of turbines are included those kinds of wheels which are constructed to utilize the *vis viva* possessed by the water in virtue of the velocity with which it arrives upon the wheel, this velocity being due to a height sensibly equal to that of the fall. The water is brought upon the buckets or blades of the turning portion of the wheel, or turbine proper, by channels distributed over the whole, or sometimes over a portion only of the circumference of the turbine; these with their various parts constitute the fixed part of the wheel, sometimes called the distributor.

Turbines may be erected upon either vertical or horizontal shafts. There are two classes of turbines with a vertical shaft. In those of the first class the water arrives horizontally upon the blades of the revolving part of the wheel through the interior of the latter, and issues horizontally, thus flowing away from the axis. This is Fourneyron's system. The revolving blades form thus a series of vertical cylindrical channels included between two horizontal walls. In those of the second class, called Euler's turbines, the water enters the wheel from above and issues from below, remaining thus at a constant distance from the axis.

Fourneyron's System of Turbines.—We will not stop to examine here the theoretical considerations involved in the conception of this kind of turbine; these considerations have been fully developed in another place. We will confine ourselves to giving a description of a turbine of this system, represented by Fig. 4053.

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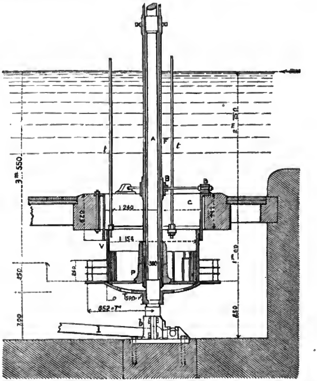

The turning portion, or turbine proper T, is erected upon a vertical iron shaft A, the lower end of which terminates in a pivot working in a socket *b*. This socket is bolted to a strong, hard stone built into the lower mill-race. A lever *l*, to which is attached an iron rod, regulates the height of the shaft, so as to remedy the wearing away of the pivot and keep the turning part of the wheel always in the same position. The vertical shaft A turns in a kind of sheath F of cast iron, bearing on its lower part the fixed portion of the wheel, or distributor P, which is furnished in its centre with a very elongated nave bored and fitted upon the sheath. This sheath F is centred and held in its position by a cast-iron collar B and three wrought-iron braces fixed as shown in the figure. The cylinder *c* serves as a guide to an inner cast-iron cylinder V, which constitutes the sluice of the turbine, and which is raised or lowered by sliding between moving and the fixed portions of the wheel. This sluice is worked by means of three vertical rods *t*, working into female screws commanded by a single piece of mechanism to ensure an equal motion of the rods. The cylinder C is bolted upon the wooden floor of the water-chamber of the turbine. The fixed part P is provided with directing blades which run from the outer circumference; half of these blades reach the centre or nave, and half stop short at the mean circumference. Their use is to direct the water into the revolving part of the wheel.

One grave defect of this kind of turbine is the facility with which plants and leaves accumulate among the fixed blades; for this reason it is necessary to place a thick screen in some part above the wheel.

Theoretically this turbine should work beneath the tail-water to avoid a loss of fall; but practically it can be submerged only by a quantity equal to the lift of the sluice. If the turbine be placed out of the tail-water, and the sluice lifted to its full height, this turbine will be placed in its normal conditions with respect to the mode of action of the water; a pressure will be established in the channels of the moving part of the wheel, and the turbine will be revolved by reaction. If, on the contrary, the sluice be only partially lifted, the mode of action of the water may be changed; the veins of water, on leaving the fixed blades, enter the channels formed by the revolving blades, the capacity of which is, in that case, too great, and disturbances are produced which cause a decrease in the duty or percentage of work of the wheel.

Some experiments made with Fourneyron's turbine at a factory at Inval (France), with a low fall, and turning under water, gave the following results;—

Lift of the sluice	$0^{m}\cdot091$	$0^{m}\cdot145$	$0^{m}\cdot200$	$0^{m}\cdot300$	$0^{m}\cdot345$
Percentage of work	0·49	0·58	0·67	0·69	0·71

From which it will be seen that the percentage of work diminishes with the lift of the sluice.

M. Fourneyron, to remove this very grave defect, divided the height of the moving portion of the wheel into three compartments (Fig. 4053), separated by horizontal partitions; but these partitions correspond to only three lifts of the sluice, and therefore remove the defect for only three particular positions of the sluice. It is a very imperfect remedy.

Among this class of turbines we must mention those of the Messrs. Williamson, of Kendal, in which the water is let into the wheel from without. Theoretically this arrangement possesses no advantage; it renders the construction of the turbine more complicated, and ought to be rejected, as well as Fourneyron's turbine itself, because it requires a volume of water and a velocity of rotation absolutely constant, conditions that can rarely be satisfied in practice.

When the fall is high, the turbine cannot in general be erected in water-chambers constructed of stone and wood, because the expense would be too great. In such a case the turbine is erected in a cast-iron tank fed by a conduit pipe from the upper mill-race. The height of the water in the upper race above the orifices of the revolving wheel must be sufficient to prevent the formation of hollows over these orifices; 1 mètre may be considered as a minimum. It is moreover necessary, for the free discharge of the water, to give a sufficient depth to the lower race beneath the wheel, to keep the mean velocity of the water there below $0^{m}\cdot60$ or thereabout. These conditions cannot always be satisfied with a turbine and an open water-chamber if the fall is rather a great one, the construction of the lower race in these cases being very expensive. This labour is considerably lessened by means of a very simple contrivance, invented and often applied by M. Girard, a French engineer.

Fig. 4054, to which we will return later, represents the application of this arrangement to one of Fourneyron's turbines. It consists of supplying the wheel by means of a siphon which raises the water to a level above that of the upper race, so that the revolving wheel may be placed up to

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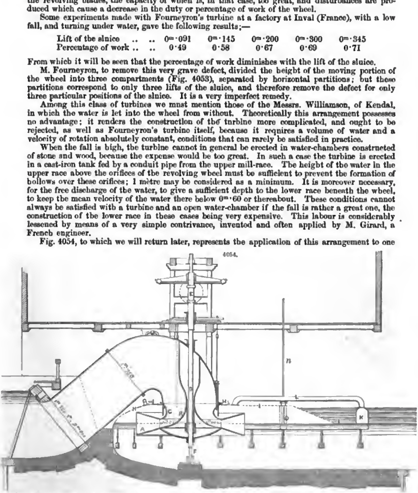


the lower level, and the formation of hollows is wholly avoided. The form of the siphon is studied with a view to guide the water in the most effective way on its arrival upon the revolving wheel, and to utilize consequently the impulsive force corresponding to the velocity which it has in the siphon.

The diametrical section of the turning wheel and the form of the blades have been modified by M. Girard, so that the turbine moves by free deviation, that is, the water flows in the buckets of the revolving wheel as in an open channel, so that the motion of this turbine satisfies as nearly as possible the theory relative to the motion of an isolated vein of water.

The sluice of the turbine represented in Fig. 4054 consists of a cast-iron cylinder, as in Fourneyron's turbine; but the diametrical profile of this cylindrical sluice is much more favourable to a proper guidance of the liquid veins: the water issues from the fixed portion of the wheel through a series of conical ajutages formed by the fixed blades, its inner wall R and that of the cylindrical sluice C. The revolving wheel A is fixed upon the bottom of a hollow cast-iron spindle or shaft D, which passes through the central casing of the tank, and terminates upwards in a kind of ear E, in which are placed the pivot and box. This box is screwed to the upper end of a central fixed shaft F, of wrought iron, passing through the hollow shaft and fixed below in a box or socket bolted to a hard stone set in the lower mill-race. This mode of construction renders the repairing and the greasing of this, the most delicate part of the wheel, very easy.

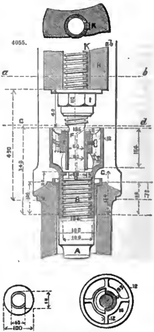
Fig. 4055 represents the details of the construction of the upper portion of the shaft D.

The pivot F terminates in a screw working into the head H of the hollow shaft, in which it is made to ascend or descend by means of the female screw I.

It often happens that the level of the lower race is variable; indeed this is the usual case. In such circumstances the turbine is placed with its lower side down to the lowest level, consequently in flood time the turbine is under water. This immersion of the revolving wheel is a favourable circumstance for Fourneyron's turbine when the sluice is wholly raised; but it is no longer favourable when circumstances do not admit of a complete raising of the sluice. And this case often occurs, because the capacity of the turbine is calculated with a view to obtain, even with a minimum fall, the power requisite for the mill. In such conditions the buckets of the revolving wheel are partially filled with the back-water, which is relatively at rest; the result is a shock and a consequent loss of work. To remove this grave defect, common to all systems of turbines, and to maintain sensibly constant the percentage of useful work in the conditions to which we have referred, M. Girard has invented a method of keeping the wheel free of water by means of compressed air driven under the revolving wheel by a small blowing machine driven by the turbine itself.

This very important improvement is shown in Fig. 4054, as having been applied to one of Fourneyron's turbines modified by M. Girard. The moving portion of the wheel is enclosed in a cast-iron cover H, perfectly air-tight, into which opens the pipe *m*, through which the compressed air is injected. The cover H runs down (I) to a reservoir of air K, in which the air collects, which is carried along mechanically by the water as it escapes from the turbine. A vertical tube *n*, terminating in a kind of reversed funnel *o*, serves to let off the superfluous air. The position of the lower edge of the funnel determines that of the *artificial* level of the water produced beneath the turbine by the injection of the air, so that the revolving wheel works in the air whatever the position of the level of the race may be. We shall see later what the advantage of this ingenious contrivance is.

Section through *a b*.



At lower end of pivot. Section at *c d*.

Euler's Turbine.—In this kind of turbine the water enters from above. To avoid a loss of fall the lower face of the revolving wheel must be down to the lowest level of the back-water. If this level is constant the turbine will be always out of the water. This kind of wheel therefore possesses an incontestable advantage over Fourneyron's, which must work constantly under water in order to fulfil the same condition.

One of the first French constructors to apply Euler's principles to the construction of turbines was M. Fontaine, of Chartres. Figs. 4056 to 4058 represent a turbine erected by him at the mill of Vadenay, with some of its principal details. The adductor channel B opens into a water-chamber formed of two side walls of hydraulic masonry and a wooden framing A, and a vertical partition D, also of wood. The fixed part of the wheel F is bolted upon the framing A; the moving part H is fixed to the lower part of a hollow shaft L, the pivot of which is arranged as in Fig. 4055. The central column or fixed shaft is let into a cast-iron support K bolted to a hard stone set in the lower mill-race. The hollow shaft is enclosed in a cast-iron casing I in two pieces, which rises a little above the highest level of the top-water. The sluice of the turbine consists of thirty-two small vertical gates V, Figs. 4057, 4058, sliding in grooves in the side cheeks of the fixed portion of the wheel; to each gate is attached an iron rod *t* fixed by two nuts to an iron ring *c*. This ring is suspended upon three or more vertical wrought-iron rods T, terminating upwards in a screw that works into the piece *m* turning in a groove. Each part *m* carries a spur-pinion; all of these pinions gear into a wheel *r*, so that by turning this wheel in either direction the rods T or the ring *c*, and consequently the thirty-two sluice-gates, are raised or lowered. Thus if it be required to reduce the discharge of water to one-third or one-fourth of the total capacity of the turbine, each of the sluices will be raised a third or a fourth of its total height.

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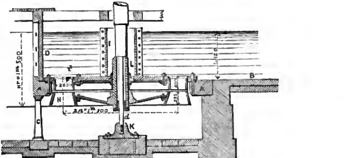

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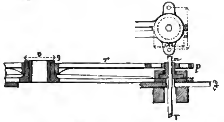

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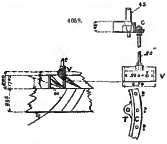

But to keep sensibly constant, notwithstanding the variations of the volume of water expended, the percentage of effective work of a turbine, the orifices of the distributor must, neglecting for the moment all other conditions, be fully opened. To make this clear we will give an example. Suppose that a turbine receiving the water throughout its circumference has to expend, during certain seasons of the year, only the half or a third of the volume of water corresponding to its total capacity. There are two ways of reducing the expenditure of the turbine so as to make it exactly equal to the volume furnished by the stream. The first, employed by M. Fontaine in the turbine which we have just described, consists in proportionately reducing the opening of all the orifices of the distributor. This is a very bad way, and it greatly reduces the percentage of work at the very time when it can least be afforded, namely, when the stream is low. The second way, the best and most rational applications of which we owe to M. Girard, consists in opening only that number of orifices which correspond to the volume to be expended; this is the principle of *partial sluices* applied to turbines. Many examples of the application of this principle were shown in the Paris Exhibition of 1867; but as all of them were very objectionable from some point of view, we will not attempt to describe them here. The Exhibition did not, indeed, show the progress which has been made during the last few years in the construction of turbines. This progress we will show in our article on TURBINES. To this end it will be necessary here to call attention to a few generalities applicable to all systems of turbines.

The form of the directing blades being given, that of the moving blades is deduced so as to allow the water to enter without shock; to effect this, the first element of the blades must be directed according to the *relative* velocity of the water at its entrance. The ratio of the *absolute* velocity with which the water issues from the orifices of the fixed portion of the wheel, with the linear velocity at the periphery of the wheel, may be taken arbitrarily; the value of this ratio has, however, an influence on the percentage of work.

If the linear velocity of the wheel is nearly equal to that of the water, the wheel is called a *high-pressure* turbine. The choice of this proportion enables us to use a wheel of a relatively small diameter, with a large volume of water. The adoption of a high-pressure turbine is often rendered necessary;—1, by the necessity of expending a large volume of water under a low fall (1 mètre and even less); 2, by the diminished cost of the wheel and the works requisite for its establishment; 3, by the advantage of obtaining a greater velocity in the shaft of the turbine, which usually simplifies much the transmission of the motion. But the percentage of work in wheels of this kind rarely exceeds 0·65. Therefore in most cases, even on rather high falls, it is better to give the turbine a velocity equal to about half that of the water. This proportion characterizes the wheels known as *low-pressure* turbines, in which the percentage of work may always be considerably greater than that of high-pressure turbines working under the same conditions of fall and volume.

The only important and rational improvements in the construction of turbines on Euler's system are due to M. Girard. Fig. 4059 represents one of Girard's turbines with an open water-chamber, the partial sluiceage of which consists of a series of vertical sluices similar to those of Fontaine's turbine explained above; but instead of their being all raised at once, they are raised one after another by means of a kind of rack and pinion communicating with a governor placed above the wheel, Fig. 4059, A B, *b*. This kind of sluice works perfectly, and may be adapted to the action of an automatic regulator.

The objection to which we called attention in the case of Fourneyron's turbine when the level of the backwater is variable, exists also in those of Euler's system. M. Girard, however, removes this objection by clearing the wheel of water by means of compressed air in the manner we have before described. Fig. 4059 shows the arrangement of the hydro-pneumatic apparatus of M. Girard applied to a turbine with an open water-chamber. Numerous experiments have been made to test its value. Some of these we give in the following Table, compiled from M. Girard's works on the subject.

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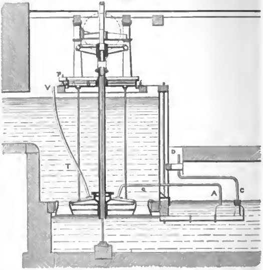


EXPERIMENTS MADE WITH THREE OF GIRARD'S LOW-PRESSURE TURBINES, WITH PARTIAL AND INDEPENDENT SLUICES, AND WORKING OUT OF THE WATER.

Description of the Wheel.	Fall.	Number of Sluices open.	Percentage of useful effect to the gross work.		Advantage of working with compressed air.
			Working out of the water.	Working under water.	
Paper Mill at Egreville (Seine-et-Marne).					
$2r = 2^m{\cdot}48$ {40 fixed curves .. 40 moving curves ($h' = 0{\cdot}30$) ..}	1·79	10 (out of 40) 0·25	0·70 to 0·75	0·58 to 0·68	$\dfrac{0{\cdot}70 - 0{\cdot}58}{0{\cdot}58} = 0{\cdot}21$
	1·63	16 " 0·40			
$T^s = 30$ horse-power under a minimum fall of 1 mètre ..	1·60	20 " 0·50			
Persian India-rubber Factory (Seine-et-Oise).					
$2r = 1{\cdot}70$ {80 fixed curves .. 54 moving curves ($h' = 0{\cdot}20$) ..}	2·710	24 (out of 80) 0·30	0·78 to 0·80	N.B.—The turbine is cleared of water naturally.	.
	2·660	32 " 0·40			
	2·535	36 " 0·45			
Spinning Mill of Amilly (Loiret).					
$2r = 3{\cdot}600$ .. .. 80 fixed curves .. .. 60 moving curves ($h' = 0{\cdot}36$)..	1·80	14 (out of 80) 0·17	0·69		
		18 " 0·22	0·71		
		24 " 0·30	0·73		
		30 " 0·375	0·77		
		36 " 0·45	0·78		
		48 " 0·60	0·80		
		48 " 0·60	..	0·70	$\dfrac{0{\cdot}80 - 0{\cdot}70}{0{\cdot}70} = 0{\cdot}14$

Fig. 4060 represents the diametrical vertical section of a turbine with an open water-chamber on Girard's system, in which the water is admitted only upon two opposite quarters of the periphery. The sluice consists of two sectors or valves *a a*, each worked by a special mechanism, one of which is shown in the figure. We ought to call attention here to the excellent and strong arrangement of the supports of the vertical shaft of the turbine as well as those of the mill-shaft.

As the two valves work *independently* of each other, only one need be opened in seasons when the water is low; this is favourable to the maintenance of a good percentage of useful effect. It is evident that this turbine which, at most, is fed upon half its circumference, must not work under water. If the level of the back-water is variable, the turbine should be placed so as to utilize the whole fall in seasons of low water; in flood time it is kept clear of water by means of compressed air.

A turbine of this kind is applicable to the case of a very variable, but not large, volume of water (1000 to 1500 litres a second at the most), with a moderate fall, or in the case of very variable volumes with a high fall. In the latter case the turbine is placed in a closed iron tank. Often the great height of the fall is not the only reason for the adoption of a closed tank. Sometimes the conformation of the place where the wheel has to be erected, or some other local reason, leads to the adoption of the iron tank, in which the water is brought by a pipe, in place of the stone and timbered water-chamber.

4060.

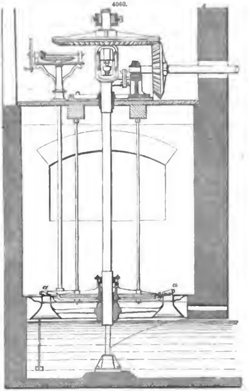
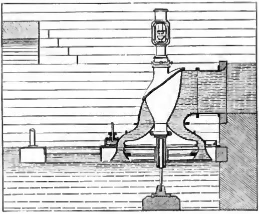


Fig. 4061 represents a turbine with a close tank on Girard's system, fixed under a low fall; the figure in question shows the arrangements to be given in such a case to the hydro-pneumatic apparatus. The wheel is fed with water throughout its periphery: and the sluice consists of ten or twelve sliding valves moving horizontally. The form of the tank is designed to enable the water to enter readily, and to prevent any loss of force through a sudden change of velocity. The motion of the slide-valves clears away any obstructions that may accumulate. As each valve corresponds to several orifices in the fixed or guiding part of the wheel, and as each valve should be fully opened in order not to reduce the proportion of useful

4061.



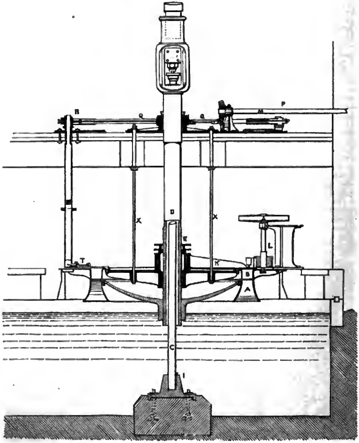
effect of the corresponding orifices, it follows that we cannot by means of this system of sluice reduce the volume of water so gradually as by means of the two independent valves mentioned above. These considerations led M. Girard to combine these two systems of sluices.

Figs. 4062, 4063, represent this arrangement for the case of a turbine with an open water-chamber. The following references will render a description unnecessary;—A, moving portion of the wheel; B, fixed portion; C, fixed column or shaft; D, hollow spindle; E, stuffing box, serving as an axis to the register-valve; K, differential register-valve with one blade covering 0·10 of the circumference; L, spindle commanding the register-valve; P, spindle commanding the toothed cam-sector; Q, toothed cam-sector working the slide-valves; R, V-piece working the slide-valves; S, hollow columns; T, movements of the slide-valves; U, copper guides; V, cast-iron slide-valves.

It will be readily seen that by uniting the slide-valves and the register-valve, we may fully open a number of orifices exactly necessary and sufficient to use only the volume of water furnished by the stream; there is at most but one, the register-valve, whose orifices are only partially covered; but this is unimportant.

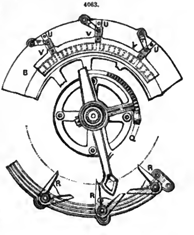
When a turbine has to expend a relatively small volume of water under a high fall (5 mètres and above), there is an advantage in supplying it with water upon a portion only of the circumference, because in that case it may have a larger diameter, and consequently revolve a less number of times than if it were supplied throughout its circumference. We may then adopt the sluice with two independent register-valves. But in many cases M. Girard prefers to supply the wheel upon only ¼ or ⅙ of its circumference in order that its orifices may be larger, and so, less liable to

4062.



be blocked up. These reasons led him to construct the turbine with a *lateral injector*, represented in Fig. 4064. The sluice of this turbine consists of a simple circular sector or valve, from which M. Fontaine first got the idea of a roller-valve. These turbines possess the immense advantage of being almost wholly open, and therefore are easily inspected, cleaned, and repaired. But it will be seen that they are not suitable to a varying level of back-water, as they cannot work under water (being supplied upon only a small portion of their circumference), and the *hydro-pneumatic* apparatus is not applicable to them.

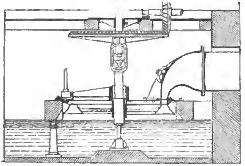
4063.



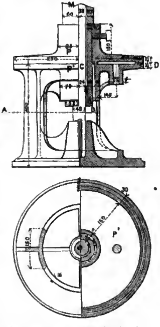
Turbines with a vertical axis possess a delicate part, namely, their pivot, which, if it has to support too heavy a load, or if it turns too rapidly, is liable to become heated. This defect is of great importance in high-fall turbines, the vertical spindle of which is often very long and heavy, and has to carry besides the weight of toothed wheels or pulleys. M. Girard has completely removed this difficulty by the application of two hydraulic pivots, represented in Fig. 4065. This pivot is placed at the bottom of the hollow spindle, that is, upon the floor of the lower mill-race.

It consists of two cast-iron plates, P and P′, provided with grooves. The upper plate P is wedged upon the bottom of the hollow spindle M, beneath the revolving wheel. The lower plate P′ is cast with the part which receives the bottom of the central column or fixed spindle; for notwithstanding the employment of the hydraulic pivot, M. Girard, as a precautionary measure, employs the ordinary pivot suspended to the upper portion of the hollow spindle, as already explained.

4064.



4065.

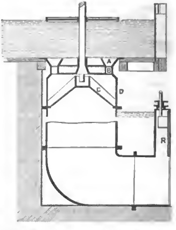


A small pipe brings the water from the upper race between the two plates of the pivot by means of the tubulure *t* cast in the lower plate. Of course the diameter of these plates must be calculated according to the weight they have to support and the height of the fall. We have seen this hydraulic pivot applied in many instances, and in all with perfect success.

Jonval's Turbine.—Fig. 4066 represents a turbine on Euler's system, with the particular arrangements introduced by Jonval. This turbine may be fixed in any intermediate point between the upper and the lower levels of the fall, taking care only to leave above the fixed portion of the wheel A a sufficient height of water to cause the water to enter properly, that is, without eddies or hollows.

The moving portion of the wheel B is wedged upon an iron spindle, the pivot of which turns in a step or bearing in the centre of a support, arranged as shown in the figure, and bolted to the tank or cistern D, which encloses the turbine and comes down to the floor of the tail-race, where it curves horizontally to allow the water to flow out. The turbine is not provided with sluices, so that the orifices of the distributor are always fully open. The expenditure of water is regulated by means of a vertical sluice-gate R, placed against the discharge orifice or the well. By closing this gate more or less, the expenditure of the turbine is diminished in proportion to the diminution of volume in the stream. This arrangement is a very bad one;—1, because it produces a contraction which occasions a loss of fall that becomes all the greater as the volume of water diminishes; 2, because the orifices remaining fully open, the velocity of the water is diminished, and the velocity of the turbine must be proportionately reduced if its percentage of useful work is to be maintained. But this condition of giving a variable velocity to the turbine is incompatible with the exigencies of most mills.

4066



M. André Köchlin has endeavoured to remove this defect by two means. The first and cheapest, but least effective, consists in reducing the breadth of the orifices by means of mitre-wedges. In this way, when the stream is low, the velocity of the water as it enters the turbine may be kept about the same, so that the velocity of the wheel may also be maintained without much variation in the proportion of useful work. But if it were attempted to make this means really effective, it would become impracticable; for as many series of wedges would be required as there were different values of the volume of water furnished by the stream. The other means, which is much more expensive, consists in erecting, upon a stream whose volume of water varies, two or three of Jonval's turbines, when a single one of Girard's, with a partial sluice, would suffice. The capacities of these multiple turbines are calculated in such a way that the quantity of water used by each shall undergo only very slight variations. In flood times, all the turbines are set going; when the water is low, on the contrary, that one only is used which has been erected specially for this season. This artifice is an excellent one for the millwright; but it increases considerably the original outlay. It does, however, possess the advantage of dividing the motive power among several wheels, which enables the mill to keep working while repairs are being executed.

As Jonval's turbine may generally be placed, in the case of moderate or high falls, considerably above the highest back-waters, they may be inspected and repaired in any season without it being necessary to draw off the water previously.

Turbines with a Horizontal Axis.—By applying the theoretical and practical rules which serve in the construction of turbines with a horizontal axis, many engineers and millwrights have erected water-wheels having a horizontal axis, which utilize the water in precisely the same way as ordinary turbines. These are generally known as *turbines with a horizontal axis.*

The Paris Exhibition of 1867 contained only two kinds of these turbines. One was exhibited by a firm of builders at Jenbach (Tyrol). But it is merely a Jonval-Köchlin turbine turned the other way up. Through a horizontal cylindrical tube, which forms the tank or well of the turbine, passes the shaft upon which the wheel is fixed. A circular channel cast in one end of this tube and perpendicular to its axis, receives the feed-pipe; the water is guided upon the wheel by fixed blades, arranged as in Euler's turbine. At the other end of the tube and also perpendicular to it is another similar channel through which the water is discharged; this orifice is provided with a valve for the purpose of regulating the expenditure of water.

These are the chief arrangements of the Jonval-Köchlin turbine. There are many objections to be urged against them. The channels by which the water is introduced and discharged being perpendicular to the axis of the wheel, there is a considerable loss of fall consequent on the sharp angles. The valve which serves to regulate the expenditure of water, by acting upon the discharge orifice, constitutes a faulty arrangement, as we have seen above; and as the wheel works constantly immersed, it must be supplied with water throughout its circumference, if the loss of work which we have already pointed out is to be avoided, and which cannot be removed here by means of compressed air. This necessity led to the adoption of the valve placed against the discharge orifice; but the remedy is a very imperfect one. Let us add, that for streams having a small volume of water and a very high fall, the adoption of this kind of turbine, as well as Fourneyron's, necessitates the giving a small diameter to the turbine, with very small orifices which are easily blocked up. Besides this, we have a great velocity in the shaft of the turbine, and consequently many chances of breakages and repairs.

Two small models of turbines with a horizontal axis on Canson's system were also exhibited. These turbines are of a very simple and primitive construction. The wheel, arranged like that of Fourneyron's turbine if its axis were placed horizontally, is erected upon a horizontal shaft resting upon two ordinary cushions. The water is directed against the lower blades of the wheel from the interior by a simple pipe, the single orifice of which is opened more or less by means of a small vertical sluice. The water is therefore very badly guided on issuing from the pipe, so that the proportion of useful work is small, hardly above 50 per cent. of the gross work expended.

This kind of turbine is, however, frequently met with in the south of France, where the progress of science has only begun to make itself felt. But it is fast disappearing from mills where a rational utilization of water-power is recognized.

Turbines with a horizontal axis possess, however, special advantages when, as in Canson's system, they receive the water upon a portion only of their circumference. These advantages are the following:—The whole periphery of the wheel being exposed to sight, it is easy to observe the way in which the water acts, and to keep the blades and the other parts of the turbine in a good condition; the absence of a pivot and all water-tight fittings for the shaft, renders the machine less delicate, allows it to revolve very rapidly without danger, and diminishes consequently the chances of accidents; as the wheel is supplied with water upon a portion only of its circumference (¼ at the most), it follows, as in the case of turbines with a vertical axis and lateral injector, that the orifices of the *fixed sector* or *injector* and those of the wheel present relatively larger dimensions, and consequently less liable to be blocked by the rubbish brought down by the water; and lastly, the level of the back-water may vary in a certain degree without lessening the proportion of useful work, since the turbine may work immersed in the back-water to a depth equal to the versed sine of the arc upon which the water is brought. But to realize all these advantages, the blades, both moving and fixed, must have all the improvements of form and dimensions introduced into the best vertical turbines.

The only horizontal turbines which satisfy all these conditions are those of M. Girard. These turbines may be applied with equal success to very high and to very low falls. The Exhibition of 1867 contained no specimen of these remarkable wheels; but we will give examples of two kinds here.

Fig. 4067 represents a small turbine on this system, adapted for a very high fall and a small volume of water. This model is equally applicable as the special motor of a machine-tool or of a lifting machine, such as paper machines, cranes, and so on. The wheel *a* is fixed upon the end of a horizontal shaft *b b*, which is provided with one or more pulleys. The water is brought through a pipe bolted upon the orifice *c* of the injector. The whole is erected upon a single bed-plate, which thus renders all the parts solid with each other.

4067.

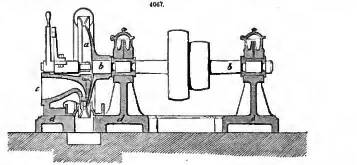
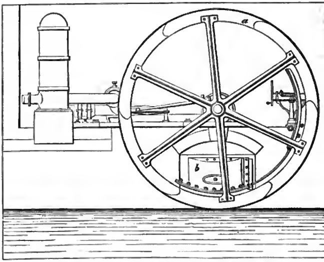


Fig. 4068 represents a large turbine which works directly and without gearing a horizontal water-pump with a plunger-piston and double action, of which M. Girard has lately made many and remarkable applications for raising water for supplying towns. It will be easily seen that this turbine may be applied (as indeed it has been) to any kind of mill. The wheel *a* is erected upon a horizontal wrought-iron shaft, and rests upon two cushions. The injector *b* supplies the turbine upon a small portion only of the circumference, which allows large orifices to be used.

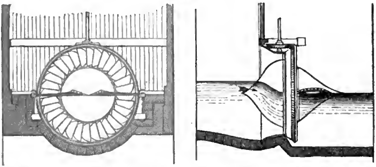
The proportion of useful work reached by these turbines may be from 75 to 80 per cent. of the gross work expended. This kind of turbine is suitable to low or moderate falls and large volumes of water. It may be advantageously substituted for any other kind of wheel required to give great power with a low fall. In support of our assertion we mention;—1, the turbines of 5^{m}·20 diameter erected by MM. Callon and Girard for supplying water to the town of Le Mans, which give each an effective power equal to 25 horse-power under a fall of 1 mètre; they make from ten to eleven revolutions a minute, and they each drive directly and without gearing two horizontal plunger-piston double-action pumps which force the water up into the reservoirs of the town. Their useful work, *in water raised*, according to the official experiments made by M. Dupuit, the representative of the interests of the town of Le Mans, is equal to 0·56 of the gross motive work of the fall; hence we may conclude that as the proportion of the useful work of the pumps is 75 per cent., that of the wheels in question is 75 per cent.; 2, the four turbines of 11^{m}·60 in diameter erected by M. Girard for the water-works of Paris, at Saint Maur, on the Marne, which supply the large reservoirs recently constructed at Ménilmontaot. Each of these wheels gives an effective power equal to 120 horse-power, under a fall that varies from 5 to 2^{m}·50. Each of them works directly and without gearing a pump similar to those described above. Experiments made upon these powerful engines by Parisian engineers have shown a proportion of useful work in water raised of 64 per cent. A remarkable peculiarity of these wheels is their sluice. It consists of a series of vertical iron gates or hatches, each worked by a piston moving in a double-action cylinder, into which the air from the pump reservoirs is let. The driver has merely to turn on or off certain cocks to raise or lower the sluices; this contrivance requires no labour, and it is capable of stopping the wheel in a few seconds. This latter quality is of great importance in case of accidents.

4068.



In bringing our remarks on turbines to a close we will give, Fig. 4069, a sketch of a particular kind of turbine with a horizontal axis, called the *screw-wheel*, designed to utilize the power of large streams having a very low fall (from $0^{m}\cdot 50$ to $0^{m}\cdot 60$) and a considerable volume of water. Two of these wheels were erected some time ago by M. Girard, at Noisiel-sur-Marne. As a reference to the figure will show, the wheel has its axis in that of the canal, and turns consequently in a plane perpendicular to the direction of the water. This kind of turbine has no sluice; the volume of water which it expends increases in proportion as the fall diminishes, and diminishes, on the contrary, in proportion as the fall increases. We think it might be very advantageously applied to our large streams, in conjunction with the large turbine-wheel described above.

4069.



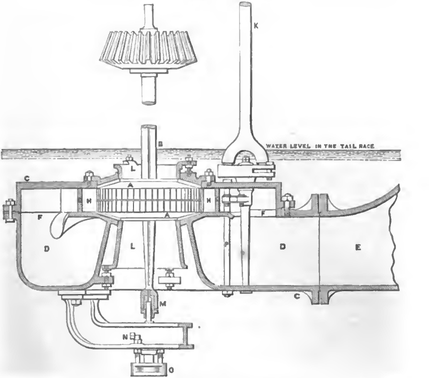
The variety of hydraulic machines that we next introduce is a water-wheel, which belongs to the turbine class, and which was invented and brought successfully into use by James Thomson, engineer, Belfast.

In this machine the moving wheel is placed within a chamber of a nearly circular form. The water is injected into the chamber tangentially at the circumference, and thus it receives a rapid motion of rotation. Retaining this motion it passes onwards towards the centre, where alone it is free to make its exit. The wheel, which is placed within the chamber, and which almost entirely fills it, is divided by thin partitions into a great number of radiating passages. Through these passages the water must flow on its course towards the centre; and in doing so it imparts its own rotatory motion to the wheel. The whirlpool of water acting within the wheel-chamber, being one principal feature of this turbine, leads to the name *Vortex* as a suitable designation for the machine as a whole.

The vortex admits of several modes of construction, but the two principal forms are the one adapted for high falls and the one for low falls. The former may be called the high-pressure vortex, and the latter the low-pressure vortex. Examples of those two kinds, in operation at two mills near Belfast, are delineated in Figs. 4070 to 4072, with merely a few unimportant deviations from the actual constructions.

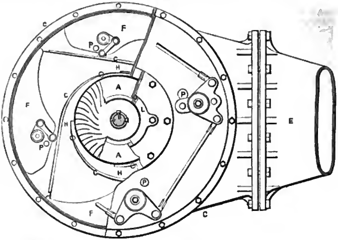
Figs. 4070, 4071, are respectively a vertical section, and a plan of a vortex of the high-pressure kind in use at the Low Lodge Mill, near Belfast, for grinding Indian corn. In these figures A A is the water-wheel. It is fixed on the upright shaft B, which conveys away the power to the machinery to be driven. The water-wheel occupies the central part of the upper division of a strong cast-iron case C C; and the part occupied by the wheel is called the *wheel-chamber*. D D is the lower division of the case, and is called the *supply chamber*. It receives the water directly from the supply pipe, of which the lower extremity is shown at E, and delivers it into the outer part of the upper division, by four large openings F, in the partition between the two divisions. The outer part of the upper division is called the *guide-blade chamber*, from its containing four guide-blades G, which direct the water tangentially into the wheel-chamber. Immediately after being injected into the wheel-chamber the water is received by the curved radiating passages of the wheel, which are partly seen in Fig. 4071, at a place where both the cover of the wheel-chamber and the upper plate of the wheel are broken away for the purpose of exposing the interior to view. The water, on reaching the inner ends of these curved passages, having already done its work, is allowed to make its exit by two large central orifices, shown distinctly on the figures at the letters L L; the one leading upwards and the other downwards. It then simply flows quietly away; for the vortex being submerged under the surface of the water in the tail-race, the water on being discharged wastes no part of the fall by a further descent. At the central orifices, close joints between the case and the wheel, to prevent the escape of water otherwise than through the wheel itself, are made by means of two annular pieces L L, called *joint-rings*, fitting to the central orifices

4070.



of the case, and capable of being adjusted, by means of studs and nuts, so as to come close to the wheel without impeding its motion by friction. The four openings H H, Figs. 4070, 4071, through which the water flows into the wheel-chamber, each situated between the point or edge of one guide-blade and the middle of the next, determine by their width the quantity of water admitted, and consequently the power of the wheel. To render this power capable of being varied at pleasure, the guide-blades are made movable round gudgeons or centres near their points; and a spindle K is connected with the guide-blades by means of links, cranks, &c., in such a way that when the spindle is moved, the four entrance orifices are all enlarged or contracted alike. This spindle K, for working the guide-blades, is itself worked by a handle in a convenient position in the mill; and the motion is communicated from the handle through the medium of a worm and sector, which not only serve to multiply the force of the man's hand, but also to prevent the guide-blades from being liable to the accident of slapping, or of being suddenly shut from the force of the water constantly pressing them inwards. The gudgeons of the guide-blades, seen in Fig. 4071 as small circles, are sunk in sockets in the floor and roof of the guide-blade chamber; and so they do not in any way obstruct the flow of the water.

4071.



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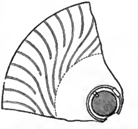


Part of the wheel, Fig. 4071, on a larger scale, to show the form of the vanes more accurately.

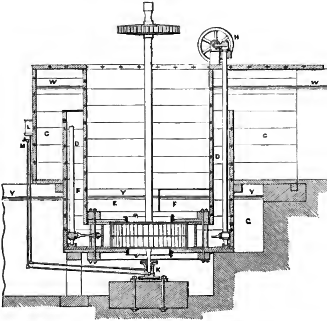
M, in Fig. 4070, is the pivot-box of the upright shaft. It contains, fixed within it, an inverted brass cup shown distinctly on the figure; and the cup revolves on an upright pin or pivot with a steel top. The pin is held stationary in a bridge N, which is itself attached to the bottom of the vortex-case. For adjusting the pin as to height a little cross bridge O is made to bear it up, and is capable of being raised or lowered by screws and nuts shown distinctly on the figure. Also for preventing the pin from gradually becoming loose in its socket in the large bridge, two pinching screws are required, of which one is to be seen in the figure. A small pipe fixed at its lower end into the centre of the inverted brass cup, and sunk in an upright groove in the vortex-shaft, affords the means of supplying oil to the rubbing surfaces, over which the oil is spread by a radial groove in the brass. A cavity, shown in the figures, is provided at the lower part of the cup, for the purpose of preventing the oil from being rapidly washed away by the water. Great stress being laid on the supposed necessity for oiling the pivots of turbines by Continental engineers, J. Thomson was led to endeavour to find and adopt the best means for oiling pivots working under water. The oiling, however, is a source of much trouble; and he has found in the course of his experience that pivots of the kind described above, made with brass working on hard steel, and with a radial groove in the brass suitable for spreading water over the rubbing surfaces, will last well without any oil being supplied.

Four tie-bolts, marked P, bind the top and bottom of the case together, so as to prevent the pressure of the water from causing the top to spring up, and so occasioning leakage at the guide-blades or joint-rings.

The height of the fall for this vortex is about 37 ft., and the standard or medium quantity of water for which the dimensions of the various parts of the wheel and case are calculated is 540 cub. ft. a minute. With this fall and water-supply the estimated power is 28 horse-power, the efficiency being taken at 75 per cent. The proper speed of the wheel, calculated in accordance with its diameter and the velocity of the water entering its chamber, is 355 revolutions a minute. The diameter of the wheel is 22⅜ in., and the extreme diameter of the case is 4 ft. 8 in.

A low-pressure vortex, constructed for another mill near Belfast, is represented in vertical section and plan, in Figs. 4073, 4074. This is essentially the same in principle as the vortex already described, but it differs in the material of which the case is constructed, and in the manner in which the water is led to the guide-blade chamber. In this the case is almost entirely of wood; and, for simplicity, the drawings represent it as if made of wood alone, though in reality, to suit the other arrangements of the mill, brickwork in certain parts was substituted for the wood. The water flows with a free upper surface, W W, into this wooden case, which consists chiefly of two wooden tanks, A A and B B, one within the other. The water-wheel chamber and the guide-blade chamber are situated in the open space between the bottom of the outer and that of the inner tank, and will be readily distinguished by reference to the figures. The water of the head-race, having been led all round the outer tank in the space C C, flows inwards over its edge, and passes downwards by the space D D, between the sides of the two tanks. It then passes through the guide-blade chamber and the water-wheel, just in the same way as was explained in respect to the high-pressure vortex already described; and in this one likewise it makes its exit by two central orifices, the one discharging upwards and the other downwards. The part of the water which passes downwards flows away at once to the tail-race, and that which passes upwards into the space E within the innermost tank, finds a free escape to the tail-race through boxes and other channels, F and G, provided for that purpose. The wheel is completely submerged under the surface of the water in the tail-race, which is represented at its ordinary level at Y Y Y, Fig. 4073, although in floods it may rise to a much greater height. The power of the wheel is regulated in a similar way to that already described in reference to the high-pressure vortex. In this case, however, as will be seen by the figures, the guide-blades are not linked together, but each is provided with a hand-wheel H, by which motion is communicated to itself alone.

4073.

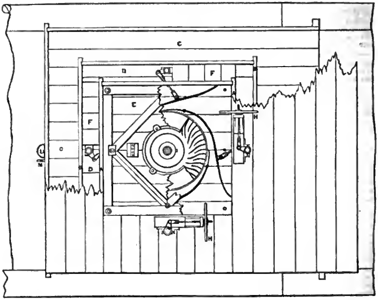


In this vortex, the fall being taken at 7 ft., the calculated quantity of water admitted at the standard opening of the guide-blades is 2460 cub. ft. a minute. Then, the efficiency of the wheel being taken at 75 per cent., its power will be 24 horse-power. Also the speed at which the wheel is calculated to revolve is 48 revolutions a minute.

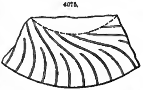
In connection with the pivot of this wheel, arrangements are made which provide for the perfect lubrication of the rubbing surfaces with clean oil. The lower end of the upright revolving shaft enters a stationary pivot-box K, through an opening made oil-tight by hemp and leather packing.

Within the box there is a small stationary steel plate on which the shaft revolves. Within the box, also, there are two oil-chambers, one situated above and round the rubbing surface of this plate, and the other underneath the plate. A constant circulation of the oil is maintained by centrifugal force, which causes it to pass from the lower chamber upwards through a central orifice in the steel plate, then outwards through a radial groove in the bottom of the revolving shaft to the upper chamber, then downwards back to the lower chamber, by one or more grooves at the circumference of the steel plate. The purpose intended to be served by the provision of the lower chamber combined with the passages for the circulation of the oil, is to permit the oil, while passing through the lower chamber, to deposit any grit or any worn metal which it may contain, so that it may be maintained clean and may be washed over the upper surface of the steel plate at every revolution of the radial groove in the bottom of the shaft. A pipe leading from an oil-cistern L, in an accessible situation, conducts oil to the upper chamber of the pivot-box; and another pipe leaves the lower chamber, and terminates, at its upper end, in a stop-cock M. This arrangement allows a flow of oil to be obtained at pleasure from the cistern, down by the one pipe, then through the pivot-box, and then up by the other pipe, and out by the cock. Thus, if any stoppage were to occur in the pipes, it could be at once detected; or if water or air were contained in the pivot-box after the first erection, or at any other time, the water could be removed by the pipe leading to the stop-cock, or the air would of itself escape by the pipe leading to the cistern, which, as well as the other pipe, has a continuous ascent from the pivot-box. Certainty may consequently be attained that the pivot really works in clean oil.

4074.



4075.



Part of the wheel, *Fig.* 4074, drawn on a larger scale to show the curvature of the vanes more correctly.

The inventor, J. Thomson, was led to adopt the pivot-box closed round the shaft with oil-tight stuffing, from having learnt of that arrangement having been successfully employed by Köchlin, an engineer of Mühlhausen. As to the other parts of the arrangements just described, he believes the settling chamber with the circulation of oil to be new, and he regards this part of the arrangements as being useful also for pivots working not under water. In respect to the materials selected for the rubbing parts, however, he thinks it necessary to state that some doubts have arisen as to the suitableness of wrought iron to work on steel even when perfectly lubricated; and he would therefore recommend that a small piece of brass should be fixed into the bottom of the shaft, all parts being made to work in the manner already explained.

The two examples which have now been described of vortex water-wheels adapted for very distinct circumstances, will serve to indicate the principal features in the structural arrangements of these machines in general. Respecting their principles of action, some further explanations will next be given. In these machines the velocity of the circumference is made the same as the velocity of the entering water, and thus there is no impact between the water and the wheel; but, on the contrary, the water enters the radiating conduits of the wheel gently, that is to say, with scarcely any motion in relation to their mouths. In order to attain the equalization of these velocities, it is necessary that the circumference of the wheel should move with the velocity which a heavy body would attain in falling through a vertical space equal to half the vertical fall of the water, or in other words, with the velocity *due* to half the fall; and that the orifices through which the water is injected into the wheel-chamber should be conjointly of such area that when all the water required is flowing through them, it also may have a velocity due to half the fall. Thus one-half only of the fall is employed in producing velocity in the water; and therefore the other half still remains acting on the water within the wheel-chamber at the circumference of the wheel in the condition of fluid pressure. Now, with the velocity already assigned to the wheel, it is found that this fluid pressure is exactly that which is requisite to overcome the centrifugal force of the water in the wheel, and to bring the water to a state of rest at its exit, the mechanical work due to both halves of the fall being transferred to the wheel during the combined action of the moving water and the moving wheel. In the foregoing statements, the effects of fluid friction, and of some other modifying influences, are, for simplicity, left out of consideration; but in the practical application of the principles, the skill and judgment of the designer must be exercised in taking all such elements as far as possible into account.

In respect to the numerous modifications of construction and arrangement which are admissible in the vortex, while the leading principles of action are retained, it may be sufficient here merely to advert—first, to the use of straight instead of curved radiating passages in the wheel; secondly, to the employment, for simplicity, of invariable entrance orifices, or of fixed instead of movable guide-blades; and lastly, to the placing of the wheel at any height, less than about 30 ft. above the water in the tail-race, combined with the employment of suction-pipes descending from the central discharge orifices, and terminating in the water of the tail-race, so as to render available the part of the fall below the wheel.

In relation to the action of turbines in general, the chief and most commonly recognized conditions, of which the accomplishment is to be aimed at, are that the water should flow through the whole machine with the least possible resistance, and that it should enter the moving wheel without shock, and be discharged from it with only a very inconsiderable velocity. The vortex is in a remarkable degree adapted for the fulfilment of these conditions. The water moving centripetally (instead of centrifugally, which is more usual in turbines) enters at the period of its greatest velocity (that is, just after passing the injection orifices) into the most rapidly moving part of the wheel, the circumference; and, at the period when it ought to be as far as possible deprived of velocity, it passes away by the central part of the wheel, the part which has the least motion. Thus in each case, that of the entrance and that of the discharge, there is an accordance between the velocities of the moving mechanism and the proper velocities of the water.

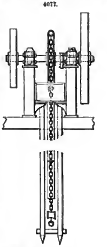
The principle of injection from without inwards, adopted in the vortex, affords another important advantage in comparison with turbines having the contrary motion of the water; as it allows ample room, in the space outside of the wheel, for large and well-formed injection channels, in which the water can be made very gradually and regularly to converge to the most contracted parts, where it is to have its greatest velocity. It is as a concomitant also of the same principle that the very simple and advantageous mode of regulating the power of the wheel by the movable guide-blades already described can be introduced. This mode, it is to be observed, while giving great variation to the areas of the entrance orifices, retains at all times very suitable forms for the converging water channels.

Another adaptation in the vortex is to be remarked as being highly beneficial, that namely according to which, by the balancing of the contrary fluid pressures due to half the head of water and to the centrifugal force of the water in the wheel, combined with the pressure due to the ejection of the water backwards from the inner ends of the vanes of the wheel when they are curved, only one-half of the work due to the fall is spent in communicating *vis viva* to the water, to be afterwards taken from it during its passage through the wheel; the remainder of the work being communicated through the fluid pressure to the wheel, without any intermediate generation of *vis viva*. Thus the velocity of the water, where it moves fastest in the machine, is kept comparatively low; not exceeding that due to half the height of the fall, while in other turbines the water usually requires to act at much higher velocities. In many of them it attains at two successive times the velocity due to the whole fall. The much smaller amount of action, or agitation, with which the water in the vortex performs its work, causes a material saving of power by diminishing the loss necessarily occasioned by fluid friction.

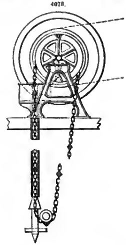
This description is the one given by the inventor. We referred, p. 1923, to the turbine water-wheel of J. Thomson as that of Williamson Brothers who are the manufacturers of it. The opinion expressed, p. 1923, is that of the experienced hydraulic engineers MM. L. Vigreux and A. Raux; see p. 140, vol. iii., of E. Lacroix's work on the Paris Exhibition of 1867. Many engineers as well as the manufacturers of this vortex water-wheel, hold a different opinion to that of MM. Vigreux and Raux. However, the matter in dispute is capable of being submitted to a mathematical investigation, which the Editor of the present work intends to institute. See TURBINES.

Chain-pumps.—Bastier's chain-pump, Figs. 4076, 4077, is very effective; 80 per cent. of the units of work applied is utilized. A vertical iron pipe descends to a little below the level of the water; an endless iron chain, carrying buckets at equal distances, works up the pipe and winds round a wheel erected on the top of the well. The buckets are provided with a pump-gear, consisting of a leathern washer enclosed between two iron discs; the diameter of the washer is a little less than that of the pipe, so as to leave a little play. The lower part of the pipe only is bored to the diameter of the washers, which at this point act as pistons. The object of this arrangement is to diminish the loss of water without causing much friction. The tube terminates upwards in a trough from which the water flows away. The motive pulley, upon which the chain should arrive tangentially, is scored to receive the links of the chain. The circumference of this pulley should contain an exact number of times the distance between two washers, and hollows should be cut in the groove to receive these washer-plugs: this prevents the chain from slipping. The chain is sufficiently weighty to require only a small guide-pulley at the bottom of the pipe.

4077.



4078.



The velocity of rotation of the wheel is at least 30 or 40 revolutions a minute, and may go up to 100, which corresponds to a velocity in the chain of $1^{m}\cdot50$ to 5 mètres a second. Whatever the inventor may say, however, we think that a high velocity is unfavourable to the percentage of work, first because the friction of the water against the sides of the pipe and the plugs increases, and second, because the water arrives at the top with a useless velocity.

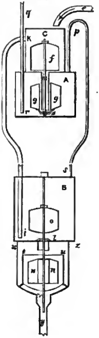
This machine is employed in mines, and with very good results. Theoretically it is adaptable to any height; but if the depth is very great, the useful effect is certainly diminished. The constructor guarantees from 80 to 90 per cent. of work, but as we have not had an opportunity of verifying these figures, we give them under reserve.

M. Durozoi's Hydraulic Propeller.—This is a simple and rustic machine, and in certain cases it may be advantageously substituted for a pump. The ascension-pipe terminates downwards in a fixed cylinder of a considerable diameter, which is sunk beneath the water. A kind of bucket fixed to movable vertical rods outside the cylinder, is moved up and down by means of these rods and a hand-lever fixed on the top of the well. At each stroke the bucket fills itself, and lifts the column of water in the ascension-pipe; as this column cannot fall back into the well, a portion of it is ejected above. The apparatus may be with single or double action, and the arrangement of the levers may be varied at will. It is applicable to any depth, since there is no suction, but it is obvious that a great length in the transmission-rods is objectionable. It is easily fixed, and rarely gets out of order. It may be used to raise dirty water, or to irrigate with liquid manures; or it may be used in tan-yards or in gas-houses, to raise the coal-tar.

Caligny's Conical Pump, without Piston or Valve.—M. Coligny has made many experiments and formed many theories respecting certain oscillating motions of water in pipes; and he has invented a great number of machines for utilizing a fall of water to raise water. We will not describe these machines here, for we do not consider them of very much value; we will merely mention one which he calls a pistonless and valveless pump. This is a simple pipe of iron or zinc, 4 mètres in length, cylindrical throughout the upper half of its length, and conical below, the diameters being $0^{m}\cdot13$ in the cylindrical portion, and $0^{m}\cdot36$ at the lower base of the cone. An alternating vertical motion given to this apparatus produces in the water in which it plunges certain oscillations which cause it to ascend to the top of the pipe, where it may be received. Considerable practice is necessary to arrive at this result. It would occupy too much of our space to explain the theory of this instrument.

Champsaur's Autodynamic Elevator.—This is in reality a Héron fountain, rendered self-acting by an ingenious arrangement of floats and valves. The water enters through a pipe *e*, Fig. 4078, into a receptacle C, and passes thence through the pipe *m* into a closed receptacle A. A float *g*, placed in this vessel, and bearing a valve *d*, is weighted so as to have a weight equal to the weight of the water which it displaces; consequently it loses its weight, but does not change its position. The level ascends into the vessel C, up to the float *f*, which, being connected with the float *g*, raises the latter, and closes the valve *d*. When the water has reached the height K, it flows off through the pipe K *i*, which takes it into a second closed receptacle B, placed at the level obtainable. As the receptacle B fills, the air which it contains is compressed, and through the tube *s p* forces the water remaining in A up the ascension-pipe *r q*. When the level of the water has reached *r*, the compressed air escapes through the same ascension-pipe, the atmospheric pressure is restored in both receptacles, the float *g* drops and opens the valve *d*, and the water begins again to fill the receptacle A. During this time the receptacle B must be emptied; for this purpose there is attached to the rod of the discharge-valve *l* a float *o*, the ascending power of which is sufficient to open this valve when the pressure upon it does not exceed that of a column of water of the height of the receptacle. So long as the air is compressed by the column of water K *i*, the valve *l* remains therefore closed; but as soon as the atmospheric pressure is restored, the float o rises, and the water flows off. The valve *l* must remain open until the emptying is complete, and to obtain this result the water is received into a system of concentric vessels *t u*, *x z*, terminating in a discharge-pipe *y*. The inner vessel has an orifice *v*, too small for the quantity of water that issues; the water then lifts the float *n*, which by its rod holds the valve open, and the latter does not close till the vessel B is quite empty.

4078.



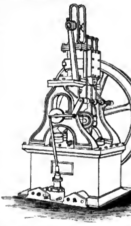
The water is thus raised in an intermittent manner in the ascension-pipe *r q*, if the various parts of the apparatus have suitable relative dimensions. The limit of the useful effect of this machine may be easily determined. Let Q be the quantity of water that arrives through the pipe *e*; H the height of the level of the vessel C above the level of the receptacle B; H′ the height of ascension above the level of the receptacle A; V and V′ the disposable volumes of the two receptacles B and A. It is evident that H′ cannot exceed H, and that it is even a little less. Moreover, by applying Boyle's law, we have $\frac{V}{V'} = \frac{H' + 10^{m} \cdot 33}{H + 10^{m} \cdot 33}$. If H′ = H, we have V = V′; but H′ being less than H, V is a little less than V′. V is the volume of water raised, V′ is the volume of water expended, and their sum is equal to Q; therefore the quantity of water raised is always a little less than the half of quantity of water made use of. As to the dynamic work of the apparatus, it is certainly very great, the loss of height of water being only equal to that of the vessel C, and the resistances being small, for they are reduced to the resistance of the valves and the friction of the water.

Though the autodynamic elevator requires a long description, it is very simple, and when clear water has to be raised, it needs but little attention. It may be of service in certain cases, such, for instance, as distributing the water supplied to a house; the level reaching about the middle of the house, about half of the quantity allowed may be raised to the upper stories, the second half, in this case, not being lost, since it may be used on the ground floor. This has been successfully done at Marseilles. The arrangement of the apparatus may be varied with circumstances, and the inventor says that with a slight modification it may be employed to raise other liquids without their becoming mixed with the motive water.

Pumps proper.—Under this head we shall include all piston-pumps with an alternating motion, with single or double action, whether worked by hand or by an inanimate motor. Reserving for a later page fire-engines, which may be grouped together, and the kind of pumps called unlimited, we will examine a number of models by the principal makers, without confining ourselves to any particular order, a simple classification being very difficult.

Common Pumps.—Scott's Steam-pumps.—Mr. Thomas Scott, of Rouen, erected two of his steam-pumps upon the banks of the Seine, for the service of the International Exhibition of 1867. Each of these pumps, or rather pumping machines, consisted of two vertical pumps with a plunger-piston, the rods of which were connected with a beam, and moved in contrary directions. One of Woolf's two-cylinder engines acted upon one end of the beam, the other carried the connecting rod of a fly-wheel common to both machines. The support of the beam was a hollow cast-iron column, which served at the same time as an air-reservoir.

4079.



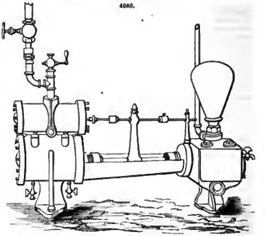
This kind of motor is well adapted, from its slow and regular motion, to the working of large pumps. It has an elegant appearance, and its motion is majestic, as the motion of this form of engine should be; but we are not at all sure that its action would continue satisfactory for any length of time. Such constructions must be very accurately made, and carefully put together.

Carrett, Marshall, and Co.'s Steam-pumps, Fig. 4079.—These machines consist of a steam-engine and a lift and force pump, with a plunger-piston, upon one frame. The kind represented in the figure, which is capable of raising 10 cub. mètres an hour to a height of 30 mètres, consists of a vertical steam-cylinder fixed in the upper part of the frame, and driving a shaft carrying a fly-wheel, which, by means of a crank, drives the plunger-piston. The frame is erected upon the water-cistern, which contains reservoirs of air for the suction and the forcing. If the steam-engine is supplied by a special boiler, a small force-pump may be added (shown in the fore part of the figure) for the service of the boiler. All the parts are put together so as to occupy a small space on the ground.

In another and smaller kind the steam-piston and the plunger have a rod in common, only interrupted by a frame for the place of the crank which drives the fly-wheel; the reservoirs of air are in the columns of the frame. These arrangements are adapted only to cases where the suction does not exceed 7 or 8 mètres. In the case of a greater height, the motor must be separated from the pump by lowering the latter into the well.

Earle's Steam-pump.—Mr. Earle, of Springfield, Massachusetts, has produced a pump, Fig. 4080, which is interesting from its thoroughly American simplicity and originality. The steam-piston and the plunger, both horizontal, are connected by a rod which is common to both. The slide-valve consists of a simple cast-iron cylinder, perfectly balanced, which lets the steam alternately upon the two faces of the piston. The piston-rod is provided with a vertical piece, which, at the end of each stroke, strikes against cleats upon the slide-valve rod, the intermittent motion of which is thus very simply commanded by the motor.

4080.

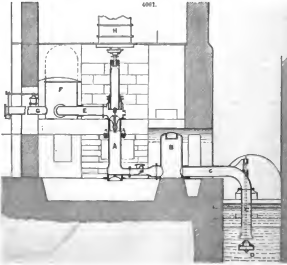


The particular arrangement of the slide-valve obviates the necessity for a fly-wheel or any revolving part, there being no dead-points; the engine is set in motion by simply turning on the steam. We may add that the various parts are arranged so as to be easily inspected, and the construction of the water-box allows of the valves being changed at pleasure; the pistons have a metallic packing, and there is a reservoir of air on the top of the water-cylinder, designed to regulate the ascension.

This pump is certainly a very remarkable one. Simplicity of construction, lightness, and consequently lowness of price, easy motion, suitability to a variable motion (a slow motion, however, gives the highest percentage of work); such are the principal advantages which recommend it to the attention of engineers.

We may here mention a ship's pump, though this belongs rather to marine engines, exhibited in the International Exhibition of 1867, and there called a steam-pump of the Forges et Chantiers

4081.



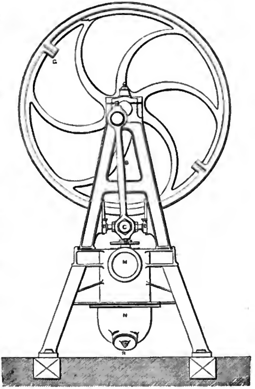
de l'Océan. The arrangement of this pump, as in the case of the foregoing, obviates the necessity for a fly-wheel, or any other revolving part; hence great simplicity of construction and an inconsiderable weight. Two horizontal steam-cylinders act directly upon two water-cylinders, the pistons being connected by rods common to both. One of the steam-pistons is always in the middle of its stroke when the other is at the end of its stroke; hence the two pistons command reciprocally their slide-valves without the medium of eccentrics or any similar contrivances. Besides this a certain regularity of motion is obtained. With a velocity of 100 strokes a minute this engine will raise 600 cub. mètres of water an hour to a height of 15 mètres.

Farcot's Steam-pumps.—To show the nature of these pumps, we will describe one used at the water-works at Angers, Fig. 4081. It is a vertical pump, the piston of which is connected directly with the piston of a steam-cylinder H above. The steam-engine is not shown in the figure, but it is of 45 nominal horse-power, and, at a speed of 16 revolutions a minute, gives an effective work in water raised of 39 horse-power.

The pump A is of single action in the suction and of double action in the forcing. This is effected by means of a double piston with a single rod; the lower end is a hollow, clack-valve piston (diameter $0^{\text{m}}\cdot48$), and the upper end, a plunger-piston, of a smaller diameter ($0^{\text{m}}\cdot35$). The common stroke is of $1^{\text{m}}\cdot20$. During the descent the water passes through the lower piston and is forced by the plunger; during the ascent, there takes place a sucking and a forcing of a volume of water depending on the difference of surface of the two pistons. The proportion between these two surfaces is calculated, regard being had to the heights of sucking and forcing, so as to produce a work about equal to the ascending and descending. The other interesting parts of the machine are: a reservoir of air B placed upon the suction-pipe C; a valve D which may be shut at pleasure; a reservoir of air F upon the forcing pipe E, with a level indicator and a contrivance for supplying the reservoir with air; and a safety-valve G with an alarm whistle.

Another system of Farcot's pumps is shown in Figs. 4082, 4083. This was erected a few years ago to supply water to the town of Lisbon. It includes two barrels or pump-chambers A, A', $0^{\text{m}}\cdot45$ in diameter, joined at the base by the vessel N. The two pistons B, B', have a stroke of $0^{\text{m}}\cdot15$; their rods are connected by a cross-piece C, connected with the cranks upon the shaft of the driving wheel G by two connecting rods D, D'. Both pistons move together and in the same direction; they are provided with similar clack-valves, but opening inversely. During the ascending motion the piston B' sucks from the tank N, and forces the water above it into the air-reservoir P, and from there to the works; at the same time the piston B, having its valves open, allows the water coming through M to pass. During the descending stroke, the piston B sucks through the pipe M and forces the water beneath B', which allows it to pass. This arrangement possesses the advantage of making the water flow always in the same direction, which is not the case with common pumps. The principle is the same as that of Stolz's twin pump, of which we will speak later, with this difference, that the pistons move simultaneously. There are no other valves than those of the pistons; these are very large, to lessen the resistance to the passage of the water. They consist of three parallel series of inclined traps, Fig. 4084, formed of metallic plates *p*, lined with leather *m* on the closing side, and with india-rubber *s* acting as a spring on the other side; the course of the traps is limited by the stops *q*. The piston B' is

4082.

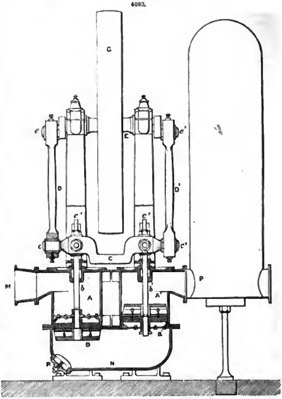


in every respect similar to B, but reversed.

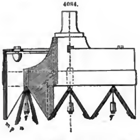
The effective work of this pump is great. For rates of speed varying from 25 to 60 revolutions a minute, experiments have shown a mean of 0·60 of work. The percentage increased with the height, and reached, for a height of 13 mètres, 0·74 for 45 revolutions, and 0·70 for 60 revolutions. The waste is from 2 to 10 per cent. It will be seen that the number of strokes may be pretty great, which renders a light motor sufficient; but the maker has been careful to choose a small stroke in order not to increase the velocity of the water at the expense of the useful effect.

As a specimen of another kind, we give in Fig. 4085 a horizontal double-action pump, the piston of which is solid, but with inner gear. The cylinder, the clack-boxes, and the air-reservoir placed on the top, form a single body, of cast iron, and very compact; the four valves may be easily inspected, and the form of all the parts is such that the water is not compelled to flow round sharp angles, a condition which lessens the resistance.

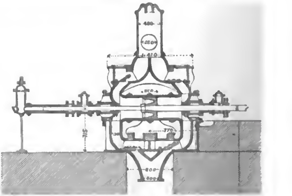
4083.



4084.

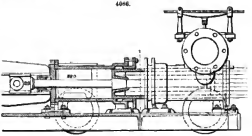


4085.



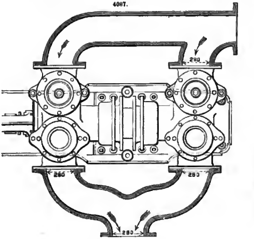
Girard's Horizontal Pump, Figs. 4086 to 4088.—This system of pump, which is designed to be worked by an inanimate motor, comprises two horizontal pump-chambers with a single piston. Each of the chambers is with single action; it is in communication with a double valve box situate at one extremity, into which the suction and delivery pipes open, so that the piston, at each single stroke, sucks the water in one cylinder and forces it in the other. The valves are well guided in their upward course, and they fall by their own weight, assisted by the action of a spring above, the flection of which may be regulated at pleasure. The suction as well as the delivery tubes are brought together upon the same conduit. The piston is a hollow cast-iron, or better, bronze cylinder, traversed from end to end by the rod, and having no external projection; it has a diameter of 0m·29 and a stroke of 0m·52. The gear or leathering is on the outside, which renders its inspection and repair easy. The whole is erected upon a cast-iron stand, on which are the piston-rod guides and the plummer-blocks of the driving shaft. This part is not shown in the figure. The design and the construction of this pump are equally good.

4086.



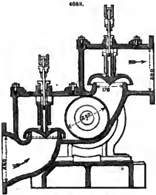
Elevation.

4087.



Plan.

4088.



Section of clack-box.

Letestu's Pumps.—M. Letestu's pumps are well known, and have been used to empty docks, among other applications. Their peculiarity is in the form of the piston, which, instead of terminating in plane faces, is composed of a copper cone pierced with holes, and covered with a piece of prepared leather rolled back upon itself and replacing the clack-valve. This leather opens during the descent of the piston, and allows the water to pass through the holes, and closes, on the contrary, as the piston ascends. The pump is thus a single-action, suction, and lift pump; the stream which it supplies becomes continuous by employing two barrels, or a reservoir at the top.

Experiments made at the Conservatoire des Arts et Métiers, gave 0·48 to 0·51 as the mean percentage of work; it reached 0·56 at low rates of speed; long strokes, with an equal velocity, are favourable to the useful effect. The waste, or quantity lost, is from 5 to 7 per cent. of the volume generated by the piston.

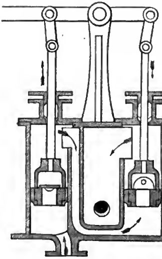
These pumps possess advantages in many cases. The piston is less liable to choke than the common pistons when thick, muddy water has to be raised; but the foot-valves at the bottom of the cylinder, possessing no peculiar feature, may act badly and stop the working of the pump. The pistons seldom get out of repair, and when they do, the repairs are easily effected. This, with the little difficulty experienced in fixing them, explains the very general adoption of these pumps. The arrangements for driving them necessarily vary with the use they are to be put to, and also with their power. The largest exhibited in the Paris Exhibition was a double, vertical, chambered pump, the chambers 0m·60 in diameter. The pistons were driven by cranks fixed upon two toothed wheels of the same diameter, driven by a single pinion. The motor was a steam-engine; a fly-wheel upon the shaft of the pinion regulated the motion, and a reservoir of air in the middle keeps up a continuous flow. The quantity of water discharged was 400 cub. metres an hour.

Nillus's Pumps.—This system, the invention of MM. Nillus, of Havre, is commonly known under the name of the *Priest's pump.* The piston is replaced by a piece of flexible leather fixed by its edges to the sides of the chamber (enlarged at this point), and having in the middle a button, to which a rod and a valve are attached. By communicating a reciprocating motion to the rod, the valve opens and shuts as the leather takes alternately a concave or a convex form, and the water is sucked up and forced out accordingly. These pumps possess the advantage of working well in thick, muddy waters. The useful effect, notwithstanding the diminution of friction due to the absence of a piston, does not exceed that of good common pumps. Experiments made with a two-chambered model, in which the leather was $0^{m}\cdot6$ in diameter and the valve $0^{m}\cdot15$, showed a mean work of 0·50. This percentage decreased as the speed increased, which is usually the case.

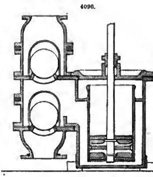
Thirion's Pump.—This pump consists of two pump-chambers with plunger-pistons, the rods of which are actuated by a beam placed above, and supported by the air-reservoir. The beam is not symmetrical; one end is carried out and jointed to a connecting rod, which connects it with a fly-wheel that receives its motion from a portable engine. Gearing is made use of to diminish the speed. The use of a beam that does not receive directly the force from the steam-piston seems to us objectionable; it uselessly increases the weight of the machine, the various parts are not sufficiently compact, which renders a large frame necessary, and the fly-wheel is placed far from the resistance, which is an irrational arrangement.

Henry and Peyrolles's Pumps.—Messrs. Henry and Peyrolles, successors to M. Stolz, of Paris, have made, in their *twin pumps*, Fig. 4089, a modification of the essential parts of a pump. This variety has two cylinders, and the pistons, which are hollow and provided with valves, move in contrary directions. The middle chamber, through which the water is forced, is in communication with the upper face of only one of the pistons. It will be seen, from an inspection of the figure, that the water, sucked up by the left piston, passes through it and then flows beneath the right piston, which forces it up into the middle chamber. Thus the water always flows in the same direction, and the resistances due to a change of direction avoided. It is true that this advantage is lessened by the fact that the water has a longer circuit to make, by which the friction is increased; but it may be driven at a greater speed than the common systems. We do not know of any experiments made to ascertain the percentage of work obtained from this pump. We will speak of the rotative pumps of this maker farther on.

4089.



4090.



The Castraise Pumps, constructed by MM. Schabaver and Foures, of Castres, Fig. 4090.—These are sucking and forcing, double-action pumps, with a single pump-chamber. The piston is leathered, but has no valves; the pump-chamber, which is either vertical or horizontal, is enclosed in a tank divided by a diaphragm perpendicular to the axis of the piston. The valves, four in number, are hollow india-rubber balls, weighted in the centre with small shot. They are arranged in pairs in two lateral boxes, a section of which is shown in the figure, the lower valve serving for the sucking and the upper for the forcing. Each half of the water-box enclosing the pump-chamber is in constant communication with the interval between the two valves of a box. In the figure the lower part of the tank corresponds with the valves represented. While the piston is sucking through one box it is forcing through the other, which is the case with all double-action pumps. The peculiarity of the Castraise pump is the use of the water-tank spoken of above, the effect of which is to render the volume of water contained in the pump much larger than the volume of the cylinder; the consequence of this is that a portion of the water acted on by suction traverses the valve-chambers only, without passing through the pump-chamber, the piston being, so to speak, always in contact with the same water. This arrangement enables the pump to work in muddy water by placing the piston beyond the reach of injury from the passage of gravel, and so on.

Experiments have given 0·56 as the mean percentage of work, the highest, for a low rate of speed, being 0·66. The waste or loss of water was from 7 to 10 per cent. The action of these pumps, the form and dimensions of which vary with their application, is very satisfactory, and their cost is not great, in spite of their relatively great weight. The makers have added to their latest models an air-reservoir, from which they expect good results.

Perreaux's Pump.—The essential character of Perreaux's pump consists in the use of india-rubber valves, cylindrical at the base and flat at the top, which gives them the form of the mouth-piece of a clarionet. Like this latter, they terminate in two lips which, under the influence of the pressures resulting from the rising and falling of the piston, open or close through the elasticity of the material. One advantage of this elasticity is that the solid matters brought in with the water may pass through without causing injury. The retaining valve is placed at the bottom of the cylinder, whilst the other, suitably extended in a cylindrical form at its base, forms a piston. The India-rubber is stiffened with ribs of the same material. The pump-chamber is of copper, and may be enclosed in wood. The upper part, which is closed, serves as an air-reservoir if the pump is simply a suction-pump; if it is to be forcing as well, a small copper cylinder placed at the side, and also provided with an India-rubber valve, forms the air-reservoir. The various parts are easily taken to pieces. These very simple constructions may be made of any form; they are of great service for agricultural purposes, and whenever it is required to raise water loaded with sand.

Motte's Bellows Pump.—The necessity of keeping the leathering in a good condition in piston-pumps has led to the adoption, for hydraulic purposes, of the principle, familiar to all, of a pair of bellows. Motte's pumps, which are frequently employed to clear the water from excavations, consist of two iron plates put together with leathern sides in exactly the same way as a common pair of bellows. They are worked by means of a beam. We have no numerical data relative to the useful effect, but there must be a considerable loss of power due to the dead-spaces in which the air is compressed and expanded uselessly at each stroke. These machines are well made, and they work very smoothly.

Armandies' Balance-beam Pump.—This pump is similar in principle to the one described above. Two pieces of wood or plate iron, at an obtuse angle with each other and provided with valves, are fixed to a kind of vertical iron beam oscillating about a lower horizontal shaft. A lever attached to the beam applies alternately the plates upon the openings of a cast-iron box at the end of the suction-pipe. The plates and the horizontal shaft are wholly under water; this prevents the heating of the parts and renders greasing unnecessary. Besides this, the valves being always visible, may be easily cleared by the hand when impure water is being raised. This pump is simple and applicable to agricultural uses, or it may be employed to clear away small bodies of water. It must be remarked, however, that it acts only by suction, and cannot be made to force, at least without introducing modifications which would destroy its rustic character.

4091.

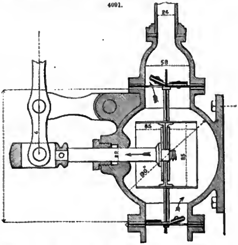


Fig. 4091 represents an excellent little pump for agricultural purposes. It is a Champonnois pump, and its peculiarity consists in its being double-actioned with a single pump-chamber.

Unlimited Pumps.—The name unlimited pumps has of late years been applied to a great number of apparatus for raising water from a depth greater than 25 or 30 ft., beyond which point suction ceases. We shall not include under this head the common plan of putting a suction-pump down a well at a sufficient level, and working it by means of rods or other contrivances. This plan is constantly made use of in deep wells, and when the depth is very great, as in the case of mines, a number of pumps are placed one above another at different levels and worked by a main rod.

Prudhomme's Pumps.—M. Prudhomme, the first, to adopt the name unlimited, invented a system in which columns of water circulating through pipes are substituted for the rods. This apparatus is composed, Fig. 4092, of two distinct parts; one placed near the motor at any distance from the well, the other fixed at the bottom of the well, at 4 or 5 mètres at the most from the level of the water; these two parts are connected by two conduit-pipes O P, R Q.

The apparatus being filled with water, which may be easily done at first starting, suppose the piston C of the upper pump moved forward. It will force the water down the pipe O P, closing the valve *o*. The pressure will be transmitted integrally to the piston K of the lower apparatus; the two pistons K and L, fixed upon the same rod, will move in the direction contrary to that of C, and will force the water up the pipe Q R, opening the valves *s* and *q* and closing *t* and *r*. As the compartments E and G have each a volume equal to that of the cylinder of the upper pump (an essential point), the quantity of water raised will be double that forced by the piston C. Only half of the total volume of water raised will go to fill the empty space B, whilst the rest will pass through the valve *p*, and enter the pipe S T. When the piston C moves in the contrary direction, the same effects will be produced the other way, and a cylinderful will be raised at each single stroke.

This pump has been applied to several mines of great depth. We do not know of any experiments made to ascertain its percentage of work; but it is probably not lower than that of common pumps, the friction of the water in the pipes being substituted for that of the long rods. It has, however, one grave defect; on account of the sudden change of direction in the motion of the water at each stroke of the piston, ramming shocks are produced which, in a large pump, might cause breakages. To lessen the chances of accident, the two conduit-pipes must be fixed very rigidly, a condition difficult to fulfil in the case of great depths.

Laburthe's Compressed-air Pumps, Fig. 4093.—M. Laburthe's pump is an extremely simple one. The pump, which is placed at any distance from the water to be raised, consists of an air-piston moving in a cylinder, which, by means of an iron pipe, is placed in communication with a box sunk in the well, and provided with a valve opening inwards. A second pipe goes from the bottom of the box to the point where it is required to discharge the water. By giving the piston an alternating motion, which is accomplished by the usual means, the compressed air in the abductor-pipe forces the water up the ascending pipe until the box is filled with air at the pressure of the ascending column. At this moment some more water must be let into the box, and to effect this a cock placed upon the upper part of the abductor-pipe is opened. Atmospheric pressure is thus restored in the box, the water of the well flows into it through the valve, and the same action is repeated. Care must be had to provide the bottom of the ascending pipe with a stop-valve. Besides this, the capacity of the box should be considerably greater than that of the ascending pipe, in order that it may not be necessary to interrupt frequently the action of the pump for the purpose of restoring atmospheric pressure in the box. This condition cannot be fulfilled practically

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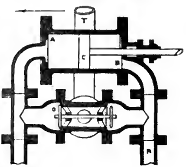

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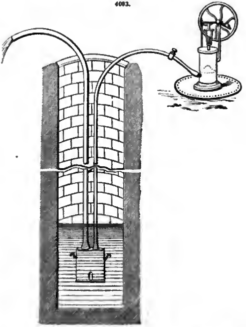
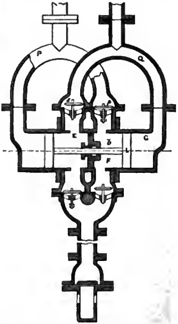




except in the case of pumps that are required to give only a small quantity of water, such as those for household purposes. Obviously the action of the pump is independent of the depth, and it is sufficient to give it dimensions proportionate to the height to which the water is to be raised. This arrangement is simple, cheap, and convenient. It is to be feared, however, that the air-pump would require great care to keep the piston air-tight, a task of some difficulty in dealing with compressed air. The percentage of work must be very low, for, by opening the cock for the purpose of restoring the atmospheric pressure, an amount of work is instantaneously lost corresponding to that requisite to compress the air in the box to the pressure of the ascending column.

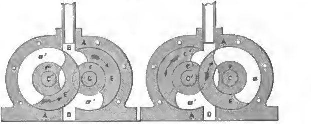
Some of the machines which we have already described might be ranged under the head of unlimited pumps; such, for example, as Durozoi's propeller and Bastier's chain-pump.

Rotary Pumps.—Revolving-piston Pumps.—As the change of direction in the motion of the water, which takes place in common pumps at each stroke of the piston, constitutes a defect that prevents the attainment of a high rate of speed, some engineers have been induced to substitute rotary pumps for them, in which this objectionable feature is absent. They consist, for the most part, of a cylindroidal box in which revolve one or more pistons, which drive the water before them; they are provided with springs arranged so as to prevent communication between the inlet and the outlet pipes. Stolz's pump, for example, is constructed upon this principle. It may be used for domestic purposes, on the condition that only clear water is raised, and that the pump is well constructed. The percentage of work is usually low.

Leclerc's pump, instead of revolving pistons, has two toothed wheels which gear into each other inside a box, and drive the water before them always in the same direction. Another system is to roll an india-rubber tube around the water-box, or, as it is more usually termed, the pump-well. This tube, which is full of water, is compressed by a roller revolving about an axis. This system, however, can be applied only on a very small scale.

There are others belonging to the same order of ideas as the preceding, but they have all the grave defects of being complicated, expensive to repair, and of little useful effect. For these reasons rotary pumps have been abandoned everywhere, except perhaps in America, where they have been more successfully treated. One of the latest improvements effected in this direction by the inventive genius of the Americans, is *Behren's Rotary Engine*, Fig. 4094, made by the Messrs. Dart and Co., of New York, which possesses some original and novel features. The inventor claims for it the merit of being at once a steam or water motor, and a pump; but it is as a hydraulic machine that it may be employed with the greatest advantage. A cast-iron box or well, A, having internally the form of two portions of parallel cylinders entering each other (as shown in the figures), is in communication at B and D with the inlet and outlet pipes. Two parallel shafts, C, C′, pass through the box, as well as two fixed cylindrical sockets, *c*, *c*′; these shafts bear on the outside a spur-wheel of the same diameter, so that they turn in contrary directions and with the same velocity. Upon the shafts are fixed two pistons, E, E′, having the form of portion of a ring concentric with the shaft and the face of the box A. The outer and convex face of these pistons rubs against the face of the cylinders A, and their lower and concave face slides upon the fixed shaft-sheaths *c*, *c*′, which are grooved to prevent the water from passing directly from B to D without impeding the revolution of the pistons. If the machine is to raise water, one of the shafts C, C′, is set in motion, and, as one drives the other, the pistons E, E′, are moved in contrary directions. By referring to the figures which represent two different positions of the pistons, it will be seen that the water entering through B will pass alternately through the annular spaces *a* and *a*′, and will be seized successively by each piston during half a revolution, whilst the other piston, as it continues to revolve, will act as a check. We have here supposed the water to enter through B, because the figure may represent the machine employed as a motor; but it is obvious that if the direction of the motion is changed, the water entering at O will ascend through the pipe B.

4094.



It is not our business to examine here the value of this machine as a motor, still less as a steam motor; but as a pump it is very serviceable. It is simple, it fills only a small space, it may work with a high velocity, and it gives, without an air-reservoir, a continuous jet. It must, however, be made and put together very carefully. It would be interesting to know its percentage of work, but we have been unable to obtain information on this point. We know only that in America it is employed in breweries and sugar-works, where it may be used to raise thick and hot liquids, on the condition, no doubt, that there be no suction of the hot liquids.

Centrifugal Pumps.—The idea of employing centrifugal force to raise water is of considerable antiquity; but Appold was the first to construct machines conveniently founded upon this principle; and so scientifically were his machines devised that even in the present day the best are those which most nearly resemble his model.

Centrifugal pumps are really water fans, formed of straight or curved blades, turning rapidly about a vertical or horizontal axis, and enclosed in a box. The water, entering through the centre of the wheel, is driven by the blades towards the circumference, and thence forced into the ascending pipe. At the same time the outward flow of the water causes a diminution of pressure about the axis, and this brings up the water from the lower reservoir. The height to which the water will ascend increases with the velocity of rotation. A simple calculation will show the relation between these two quantities. Calling the velocity in mètres a second at the end of the blades V, the extreme radius of these blades R, the number of revolutions a minute N, the weight of the water passing a second P, and the height of elevation H, we find (either by the expression of the centrifugal force, or by that of the *vis viva* due to the velocity V), neglecting the friction, that the work developed is $\frac{PV^2}{2g}$. This work, multiplied by the coefficient of the percentage of work, must be equal to the work effected, say PH, $K\frac{PV^2}{2g} = PH$; whence $H = \frac{1}{2g}KV^2 = 0{\cdot}051\,KV^2$. If it be required to introduce the number of revolutions into the formula, $V = \frac{2\pi RN}{60}$; whence $H = 0{\cdot}00056\,KR^2N^2$. Experiments have given, in the best centrifugal pumps, $K = 0{\cdot}65$; whence we deduce

$$H = 0{\cdot}034\,V^2 = 0{\cdot}00056\,R^2N^2.$$

Appold's formula is $V' = 550 + 550\sqrt{H'}$, V' being the velocity at the circumference in English feet a minute, and H' the height also in English feet, which gives, as the velocity in mètres a second, H being also expressed in mètres, $V = 0^{m}{\cdot}84 + 4{\cdot}98\sqrt{H}$; the formula which we have established above leads to $V = 5{\cdot}42\sqrt{H}$. These two values of V agree sensibly for the ordinary values of H.

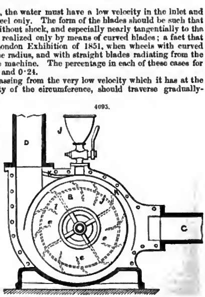
It is obvious that the velocity of these machines is necessarily great; they are therefore especially suitable for raising large volumes of water to a small height. An increase of velocity may either raise the water to a greater height, or increase the discharge.

The height of suction should be small, because the ascent of the water being due to the excess of atmospheric pressure above the pressure at the centre of the wheel, this excess must impart to the water a velocity sufficiently great to satisfy the discharge. If this condition is not fulfilled, the water does not enter in sufficient quantity, the machine gets out of water, and of course ceases to work. When circumstances will allow of it, it is well to avoid suction altogether, by placing the pump beneath the level of the lower reservoir; in which case the velocity of rotation may be increased without emptying the pump.

To utilize satisfactorily the motive work, the water must have a low velocity in the inlet and delivery pipes, and a high velocity in the wheel only. The form of the blades should be such that the fillets of water may enter them almost without shock, and especially nearly tangentially to the outer circumference. This condition can be realized only by means of curved blades; a fact that was proved by experiments made in the London Exhibition of 1851, when wheels with curved blades, with straight blades inclined upon the radius, and with straight blades radiating from the centre, were successively placed in the same machine. The percentage in each of these cases for a height of from 15 to 18 ft. was 0·67, 0·42, and 0·24.

It is also necessary that the water, in passing from the very low velocity which it has at the centre of the wheel, to the high velocity of the circumference, should traverse gradually-diminishing sections. In the same way the sections of passage must increase from the point where the water issues from the blades to the ascent-pipe. By thus making the sections inversely proportional to the velocities, the eddying and whirling, which absorb a portion of the work, are avoided. The first result may be obtained either by varying the thickness of the blades so as to give their concave side a different form from that of their convex side, or, as in the case of Lloyd's fan, by making the blades of a uniform thickness, and by diminishing their breadth from the centre of the wheel. The blades are in this case enclosed between two lens-shaped covers widening towards the centre.

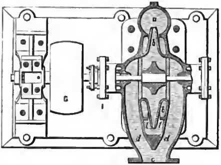
4095.



We will examine here some of the best models.

Neut and Dumont's Centrifugal Pumps.—These closely resemble Appold's type; the water brought in by the conduit-pipe C, Figs. 4095, 4096, at the height of the axis, separates into two currents *d* that lead it to

4096.

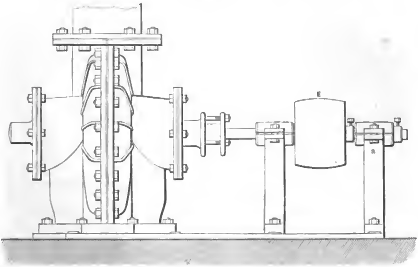


the centre of the wheel, which is formed of two cheeks *b*, between which are the blades *c e*; some of these reach to the nave and are fixed to it, their breadth diminishing from the centre to the circumference. Some circular partitions force the water issuing from the wheel to follow an annular conduit K, the section of which increases progressively up to the ascent-pipe D; this *partly* realizes the conditions indicated above. The body is formed of two symmetrical pieces bolted together; it is traversed by the horizontal shaft X which passes through stuffing boxes and carries the transmission pulley G. The whole rests upon a single bed-plate I. The funnel J serves to fetch the pump at starting. The orifice K′ gives an outlet to the air which may lodge itself in the upper portion. To prevent the air from getting through the stuffing box, the latter is put in communication with the delivery column by means of a pipe constantly filled with water; and, in case the air should get into the centre through the suction-pipe, in order to fetch the pump again without stopping it, two holes are provided which put the centre of the wheel in communication with the interior of the chamber into which the water is forced; this forces the air to escape.

During some experiments made to ascertain the percentage of work, one of these pumps, having a diameter of wheel of $0^{m}\cdot300$, with suction and forcing orifices $0^{m}\cdot250$ in diameter, raised 138 litres a second to a total height of $5^{m}\cdot50$; the velocity being 500 revolutions a minute, the mean percentage of work was 57.

Centrifugal Pumps of Messrs. Gwynne and Co., of London.—These complete and powerful pumps were originally constructed with straight blades, radiating from the centre and provided with a circulation-pipe; but the percentage of work was very low, only 19. Later, profiting by the lessons taught by the Exhibition of 1851, they modified them in the direction of Appold's plan, by curving the end of the blades so as to bring them almost tangentially to the circumference of the disc. This is shown in Figs. 4097 to 4100, which represent a pump of $0^{m}\cdot460$ in diameter. The water entering through H, separates into two currents H′ and H″, which enter through the centre of the wheel K′, K″, to issue through the circumference and flow thence to the pipe Z. The blades, six in number, only three of which reach the nave, are of cast iron 14 millimètres thick, curved and bevelled on the outer circumference so as to be only 1 millimètre thick at the

4097.



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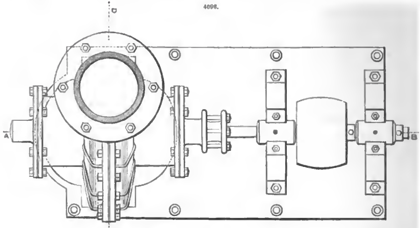
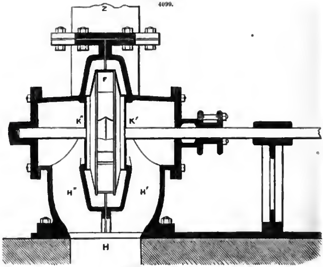


Plan.

4099.

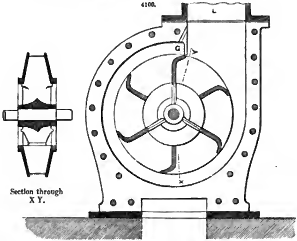


Section through A B.

end. They are also a little rounded where the water enters, but they remain normal to the nave; this lessens the useful effect in consequence of the shocks of the water. The breadth of the blades and their envelope, at first uniform, decreases afterwards up to the end, so as to produce a section varying in an inverse direction to the velocity of the water at different distances from the centre. On issuing from the wheel, the water first passes through an annular space which takes it to the delivery-pipe. A diaphragm G prevents a partial return of the water into this annular space, and an orifice furnishes an outlet to the air which tends to collect at G.

This pump was subjected to experiments at the Conservatoire des Arts et Métiers at Paris, for the purpose of ascertaining its percentage of work. The diameter was $0^{m}\cdot460$. The height of aspiration was $0^{m}\cdot80$, and the forcing height $9^{m}\cdot50$. The number of revolutions varied from 630 to 700 a minute. The maximum useful effect was 0·52, corresponding to 670 revolutions, and to 7 litres of water raised by each revolution. The minimum was 0·32, corresponding to 640 revolutions and 4·75 litres a revolution. The gross mean may be fixed at 0·45.

4100.

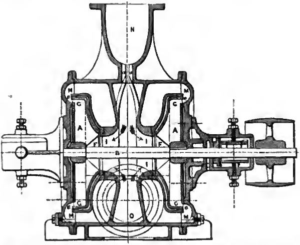


Section through X Y.

Section through C D.

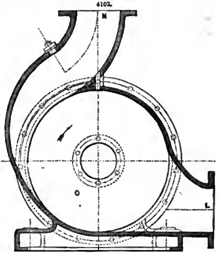
Coignard and Co.'s Centrifugal Pumps, Figs. 4101, 4102.—In these pumps, Messrs. Coignard and Co., of Paris, have substituted for the blades in Appold's machine, two revolving pieces A, which they call screws, placed symmetrically upon the spindle D. The water, brought through the pipe L O to the centre of the wheel I, passes through the orifices F into the screws, which impart to it an increasing velocity up to the circumference at G; thence it flows through the conduits M into the common ascending pipe N. The small orifices *a* afford an escape for the air which may collect at the top of the pump. The form of the screws is such that the section of passage decreases from the centre to the circumference, and increases from the issues M up to the delivery-pipe, so as to vary inversely with the velocity. This condition is favourable to the work of the pump, as we have seen above, but the sharp angles, as G, *e*, M, must cause a slight resistance. The construction of these pumps is certainly good; the axis passes through two stuffing-box glands P, the pressure of which may be regulated at pleasure. The whole rests upon one bed-plate.

4101.



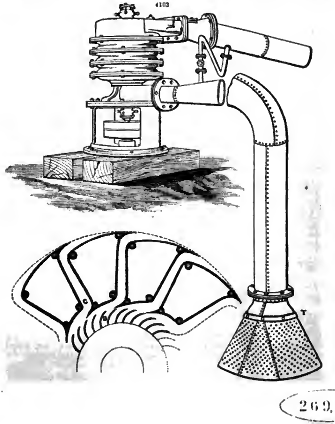
Centrifugal pumps are very serviceable when the height of ascension is not great. They possess the advantage of being adaptable to a varying discharge, and even a varying height, a change of velocity being all that is necessary to render them adequate to the case in question. They are easily

4102.



erected and removed, and the absence of valves, except the foot-valve when there is suction, renders them capable of raising dirty water. They always require an inanimate motor. Their chief defect is their great velocity, which cannot be increased above a certain limit without injury to the stuffing of the axis. Attempts have been made to overcome this difficulty, in cases of a great height, by placing several centrifugal wheels upon the same spindle, the water forced up by the first entering into the axis of the second, which takes it up to the third, and so on. The consequence of this is, that the increase of pressure produced in each wheel is added to the others, and that the final pressure for a given velocity increases with the number of discs. This ingenious idea was first applied by John Gwynne; he succeeded in this way in increasing the height of elevation without increasing the velocity of rotation, but at the cost of useful effect. There was a loss of work in passing from one wheel to the other, on account of the sudden changes in the sections of passage, and in the direction of the plan of the water. M. Girard has improved the construction of this machine, and named it the "Lifting turbine," drawings of which are given in Figs. 4103, 4104. It consists of a number of similar wheels, placed one above another and

4103



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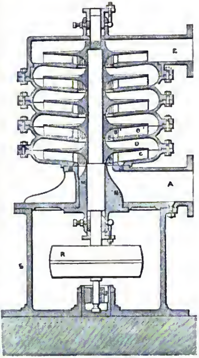
fixed upon a vertical spindle, the whole being enclosed in a cast-iron casing forming partitions between the wheels. The water entering through A is sucked up to the centre, B, of the first wheel, and driven along C D up to the centre, E, of the second, which in its turn drives it along B' D', and so on up to the delivery-pipe E. The curves of the blades and of the envelope, or casing, are carefully studied, with a view of making the sections of passage vary progressively, according to the velocity which the water is to have in them, and so to lessen the effect of the sudden changes of direction and of velocity. Each wheel contains 36 curved directrices, B, corresponding to which are 12 channels, C. As details of construction, we may remark that the arrangement of the pivot and collars of the spindle is such that they may be regulated at pleasure; that the tube placing the delivery-pipe in communication with the suction-pipe is intended to prevent the pump from getting out of water in consequence of the entrance of air, and that the rose T at the end of the suction-pipe is for the purpose of keeping out solid matters, which might cause a breakage.

4104.



Section through the axis.

Experiments were made with this machine at the Conservatoire des Arts et Metiers, at Paris, the height of suction being, in this case, $1^m \cdot 74$, and the height of delivery varying from 4 to 10 mètres. The following are the means of the results obtained from a model constructed with the latest improvements in details:—

Number of revolutions a minute	300	400	400
	mètres.	mètres.	mètres.
Height of delivery ..	4	4·20	7
Volume of water raised a minute	2800 to 4000 litres.		
Percentage of work ..	0·35 to 0·40.		

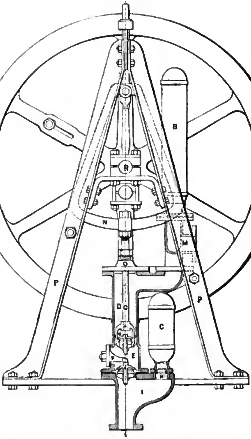
These figures show that, for a determinate height of delivery, the velocity is considerably less than that of a centrifugal pump with one disc; but this advantage is obtained by a loss in the percentage of work, and it must be added that the machine is heavier, and consequently more costly and less convenient.

The India pumps, designed and manufactured by Merryweather and Sons, London. These pumps are termed *India pumps* because they are much employed in *India*.

Fig. 4105 is a side elevation of this pump, with the pump-barrel, valves, and suction-breech in sections, Figs. 4106, 4107. A is a stout cast-iron fly-wheel, which is the only piece of cast iron about the whole machine; B is the copper delivery air-vessel, which steadies the stream of water when pumping through a hose, if used as a fire-engine, or when used as a pumping engine prevents concussion in the discharging main; C is a copper suction air-vessel placed in the suction-breech of pump; D, pump-barrel, of which there are two; E is the valve-chamber at lower end of pump; F is the door of the valve-chamber, with a stop-piece to regulate the lift of valve in suction; G is a copper pump-rod, connected at lower end to the spindle-bucket, and at upper end to the kite; H is the passage from breech-chamber to suction air-vessel; I is the suction-breech of pump; J is the suction spindle-valve complete, with its valve-seating arranged so that the whole can be taken out of the pump in one piece if required; K is the bucket fitted with spindle-valve and leather cup, L; R is the crank of motion, working on gun-metal bearings, and mounted on wrought-iron cross-bearers bolted to framing; M, the delivery-piece of pump, to which either flanged pipes may be attached for filling tanks or a screw connecting-piece to receive hose; N, the wrought-iron kite motion to which connect the guide-rods at top and the pump-rod at bottom; O is the gun-metal cover of pump, fitted with stuffing gland and nut; P P, the wrought angle-iron frames carrying the whole of the machinery.

Fire-engines.—Though fire-engines are a kind of forcing pump, yet they differ from this latter in the conditions which they have to fulfil. In the common forcing pump, we give to the water the least velocity possible, in order to utilize to the fullest extent the motive power employed; but in the case of a fire-engine, on the contrary, velocity is the chief object in view. The water has to be thrown to a great height, and in such a way that the jet may overcome the resistance of the air without being divided into spray too soon. The velocity of issue, for given dimensions and number of strokes, depends on the diameter of the orifice of the spout-pipe, and this diameter must be made proportionate to the volume of water to be thrown, and to the distance or length of jet. In 1862 [illegible]periments were made in London for the purpose of ascertaining the influence of the size [illegible]e jet

4106.



upon its efficiency. These experiments, made with some English pumps and a Letestu pump. led to the conclusion that a large diameter at the end of the spout-pipe is favourable to the effect which it is required to produce, namely, to throw the water to a great horizontal and vertical distance without losing any of it. Thus the English pumps, with an orifice of 20 or 22 millimètres in diameter, were effective at a distance one and a half times greater than that of the French pump with an orifice of 14 millimètres, and the ratio of the quantity of water utilized to the quantity thrown from the spout-pipe was greatly superior for the former. We have no figures relative to the *work* of a fire-engine; but the matter is not one of great importance. Probably 30 per cent. would not be far wrong for the best-made engines.

Steam fire-engines were first used in America. A capital point in this kind of engine is the necessity of having a boiler capable of producing a sufficient quantity of steam in the least possible time, and to this point makers have chiefly directed their attention.

Lee and Larned's Steam Fire-engine.—The Messrs. Lee and Larned, of New York, were the first to construct an engine of this kind. It is provided with a vertical boiler similar to Field's system, that is, furnished with vertical water-tubes closed at the bottom and in communication at the top with the principal body. These tubes are placed in the fire-box, which is itself surrounded by sheets of water; concentric with the first are other tubes, open at both ends, which keep up, in consequence of the decreased density of the heated water charged with steam, a very active circulation, and consequently a rapid vaporization. The pump is rotary, and is driven by a steam-piston having a reciprocating motion and a short stroke. Two fly-wheels served to carry the pump over the dead-points; the whole machine fills only a small space, and it works at a high rate of speed. The engine, with its frame, is carried upon four wheels; the boiler rests directly upon the back axle through the medium of a spring; the remainder of the engine rests upon the fore axle by means of two springs.

Mazeline's Steam Fire-engine.—To the Messrs. Mazeline, of Havre, is due a modification of Lee and Larned's system. In the place of rotery pump, they have substituted two horizontal water-cylinders, with plungers driven directly by two pistons. The common stroke is 0m·220, the diameter of the plungers 0m·152, and that of the pistons 0m·236. The valves are worked directly by rods, without the medium of eccentrics. There is no fly-wheel, nor any revolving parts. The boiler is vertical, and has a heating surface of 22 square mètres.

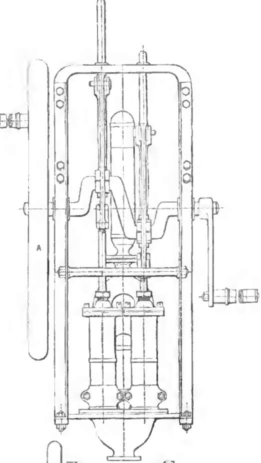
Steam Fire-engines of Merryweather and Sons, Engineers, London, Figs. 4108 to 4112.—Merryweather's lesser engines comprise a horizontal double-action pump worked directly by the steam piston-rod T, Fig. 4110. The slide-valve is worked by the piston-rod, and there is no fly-wheel. The boiler, which is placed behind, is one of Field's system, Fig. 957, like those of the American engines. The whole rests upon a strong iron frame supported upon wheels by means of springs. Seats for the firemen are placed in front, and a reservoir of air completes the engine. See ENGINES, VARIETIES OF, p. 1429, Figs. 2729 to 2732.

The large engines of Merryweather are the same in design, but double. They contain two horizontal direct-action water-cylinders B B, Fig. 4109, and the same number of steam-cylinders. The distribution of the steam is effected as in the small engines, by means of the rods; there is no fly-wheel. The boiler, as in the former case, is one of Field's, and may be fed either by a Giffard injector or by a small pump, which is preferable.

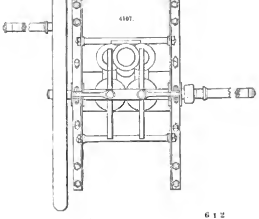
The points to be remarked in these engines are the good construction of the boiler, which is capable of getting up steam in a few minutes while on the way to the fire, the suspension combined so as to cause but little oscillation, the long stroke of the pistons and the large volume of water thrown at a stroke, which allow of a reduction in the velocity.

At the Paris Exhibition

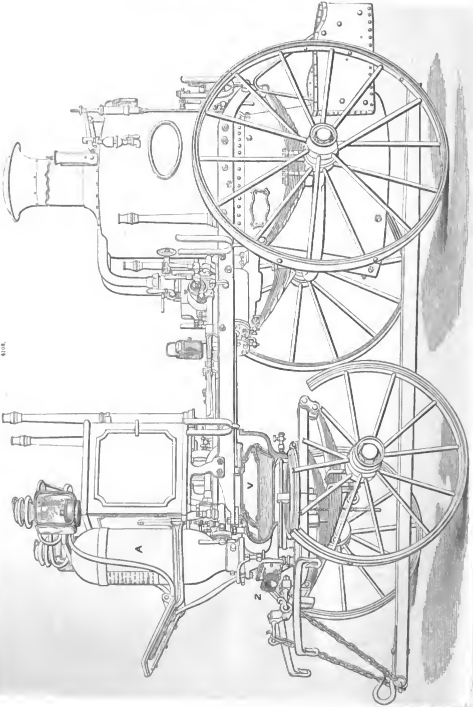
4106.



4107.



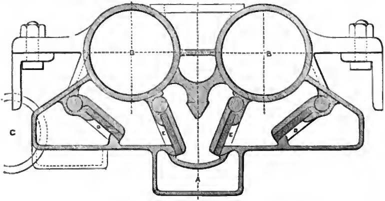
4108.



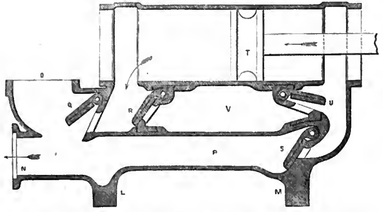
of 1867, experiments were made with the engines described above, and one of Shand and Mason's engines. The water was taken from the Seine through a suction-pipe $2^{m}\cdot 50$ long, the delivery being 100 mètres. The lighthouse served as an object to measure the height of the jets by. The boilers having been filled with cold water, the fires were lighted. In 10½ minutes, Merryweather's boiler reached a pressure of seven atmospheres. The engine was then started, and the pressure having increased, maintained itself for an hour between eight and nine atmospheres. Shand and Mason's engine was 13 minutes in getting up steam, and the jet was irregular, especially at starting. One of Mazeline's large engines was then tried against a Shand and Mason; the former was unable to keep up the pressure, and the latter worked badly. On the following day, Merryweather's large engine worked alone throughout the whole day, and in a very satisfactory manner. It threw the water with great regularity either in one jet of 45 millimètres or in four jets of 25 millimètres. We have carefully examined most of the hydraulic machines, termed steam fire-engines, employed in Europe and America to extinguish fires; each of those machines possesses one, two, or more peculiar points of excellence, but the only engines that satisfy all the required conditions are those of Merryweather and Sons, of London. These engines can remain longer neglected and out of use, without impairing their action, than any other fire-engine which we have examined; this essential property is often overlooked when the relative merits of these hydraulic machines are being compared.

Figs. 4109, 4110, are sections of one of Merryweather's improved double-cylinder steam fire-engine pumps, with doors placed at ends, so that the valves and their seatings can be drawn out in

4109.



4110.

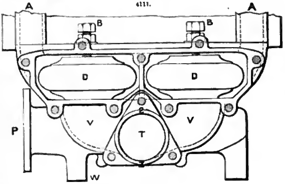


a few minutes in their entirety. The valves and water-passages are below the pump-barrels, and as the pump is entirely empty when the pump is at rest, there is no fear of its being affected by the frost. Another point of advantage in this class of pump is that the barrels will work both foul and gritty water without injury; throughout the passages are very capacious, and being unobstructed by gratings will pass muddy water, sea-weed, or any other foreign matter that is in the water. The pistons of this class of pump are self-lubricative, and seldom want attention, if any; and this is a feature that has never before been obtained in double-acting pumps.

A, Fig. 4109, is the delivery of pump; B B, pump-barrels; C, the suction-inlet of pump; D D, the suction-valves; E E, the delivery-valves. The body of the pump is of one entire casting, and of gun-metal.

In Fig. 4108, V shows the position of the valve, of which Figs. 4109, 4110, are sections; A, Fig. 4108, is the air-vessel. The piston T, Fig. 4110, moving in the direction of the arrow, half its stroke being made; the valves U, Q, are open, and R and S closed. The valves Q, U, are closed and R, S, opened when the piston T makes its return stroke, but the delivery, through P N, is continuous and in the direction of the arrow N. O, Fig. 4110, is the passage-pipe to the air-vessel A, Fig. 4108. The valve-cover and the supports L, M, are cast in one piece. In our article, Engines, Varieties of, p. 1430, we referred to Merryweather's valves, Figs. 4111, 4112.

4111.



4112.

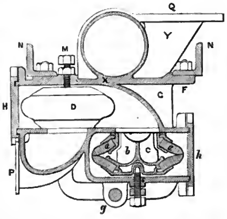


Fig. 4111. A A are the openings from the valves to pump-barrel; B B are the screws for holding the valves, and adjusting the same; D D are the disc lip suction-valves of Field; P is the discharge or outlet passage from pump; S the face of cover for side suction; T, suction-passage; V V, suction-passage leading direct to valves; W, bracket for fixing pump; Z, suction-flange.

Fig. 4112. *a*, *a*, the india-rubber disc lip-valve of Field; *b*, *c*, gun-metal guide for valve; D, suction-valves; F, flange or leg for fixing pump to frame; G, water-passage; *g*, bracket for fixing pump to frame; H, *h*, suction and delivery covers; M, the screw for holding valve, and adjusting the same; N, angle-iron frames, to which pump is bolted; P, suction-passage; Q, delivery air-vessel flange; S is same as M; X, body of the casting of pump; Y, delivery-passage.

Centrifugal Pumps, Figs. 4113 to 4121, *of John and H. A. Gwynne, of Hammersmith.*—Of all the centrifugal pumps, and they are not a few, these we select as they are very durable and mechanically complete; they are hard to be disarranged, but easily repaired.

We take the following description from the specification, 30 July, 1868, of John Gwynne and Henry Anderson Gwynne, of Hammersmith:—

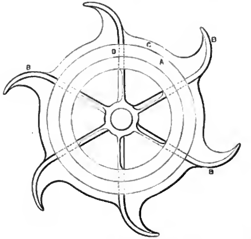
The improvements in the construction of centrifugal pumps, Figs. 4113 to 4121, consist in the making of the impeller without the usual discs or side plates. This impeller Messrs. Gwynne prefer to make of cast steel, thus forming a much lighter and equally strong motor. This form of impeller is especially adapted to the form and construction of centrifugal pumps ordinarily made by this firm.

In order to vary the speed between that of the engine-shaft and the centrifugal pump, the inventors propose to employ a novel arrangement and construction of frictional wheels with one square or angular-shaped groove in the one and corresponding projection upon the other fitting into the aforesaid groove, the amount of friction between the wheels being regulated in the following manner;—The wheel with the square or angle-shaped groove is divided into discs, and when in working order these discs are separated from one another a short distance, and held in that position by bolts and nuts, or a traversing central nut. When from any cause it is required to vary the amount of friction between the wheels, the bolts holding these discs are tightened or slackened accordingly; or, in other words, the lateral distance between these discs is varied. If preferred, the wheel having the projection may be similarly varied, or each wheel may have grooves and projections upon their faces alternately. There may be several such discs or grooved and beaded wheels mounted on the same shaft or shafts at any convenient distance apart. These wheels may be used for driving other descriptions of machinery, and employed for the purpose of transmitting motion.

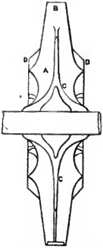
For the purpose of condensing the exhaust steam of the engine working the pump, the inventors make the suction or delivery pipe of the pump, for a certain portion of its length, of thin metal, and enclose this length within a casing of greater diameter than the pipe, so that an annular space or chamber is formed by closing it at each end. This annular space or chamber forms a condenser for the exhaust steam from the cylinder of the engine, which, upon being caused to pass into it, is immediately condensed by contact with the cold metallic surface;—maintained cold by the circulation of the water passing through the internal pipe. An air-pump is fitted to this annular condenser in the usual manner, or this water may be removed from the condenser by having a vertical pipe leading downwards of sufficient length, a steam trap being placed at the bottom of it, or by a pipe leading into the suction-pipe of pump, a vacuum being formed by the velocity of the water. If preferred, the condensing chamber may be enlarged and the inside pipe perforated so as to condense the steam more rapidly, a combination of the water-jet and surface condensation being effected within the same vessel; or the exhaust steam may be blown directly into the discharge or suction pipe of the pump. The pipe of the centrifugal pump, where used as a condenser, may be corrugated or fluted to expose a larger surface or area, or the suction-pipe may be enlarged and two or more pipes introduced therein. This condenser or a second condenser upon another portion of the suction or delivery pipe of the centrifugal pump may be used for the purpose of condensing the steam of any other engine conveniently near, instead of, or in addition to, the driving engine employed for working the pump. This form and arrangement of surface condenser is also applicable to the pipes of any other pumps and to other hydraulic machinery, through which or by means of which a considerable current of water is produced or set in motion.

Fig. 4113 is a side elevation, and Fig. 4114 a front sectional elevation, of the disc or impeller A, which in this case has six arms B, but any other number of arms may be employed; these arms are cast in one piece with the boss. A centre plate C springs from the boss, gradually decreasing in thickness until at the termination of the radial portion of the arms, the plate finishes with a knife-edge, or as thin as practicable, the object of this plate C being to separate the currents of water upon each side of the disc without producing an eddy or reflux. The arms are radial for about two-thirds of their length, curving off towards the periphery in an opposite direction to the line of rotation. Two rings D, one at each side of the arms, form the bearing surface, and we prefer to make the entire impeller or disc of one casting. Figs. 4115, 4116, are side and front sectional elevations respectively of the pump casing E, with the impeller or disc A fitted in position; F F are the suction-passages which branch off from the suction-pipe G at the point *g*. To prevent any obstruction to the water this bottom part of the casing E is thinned off to a knife-edge, as shown at *g*, and a space is left between the passage and the case to carry the suction-pipes F F over the enlargement of the discharge-passage in a straight line to the openings in the centre of the disc A, at which point they curve into the top of these openings. The discharge-passage is sprung from the periphery of the disc in the form of a helix or volute, commencing at the top of the case *e*, and gradually increasing at e^{I}, e^{II}, until at e^{III} it reaches the full size of the discharge-pipe. That

4113.

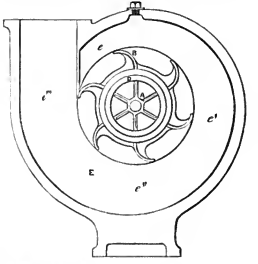


4114.

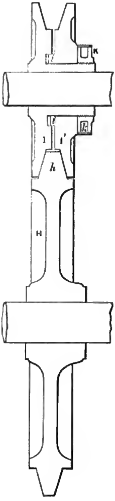


part of the pump casing E which contains the impeller A is made of the same shape as the profile of the impeller, and similar in section, and of just sufficient size to permit the impeller to revolve, as shown in Fig. 4116, the bearing rings D being accurately fitted to the turned recesses in the casing. By this means the usual side plates on the discs of centrifugal pumps are not required, the peculiar form of the pump casing, as hereinbefore described, acting in the place of such plates, consequently the friction of the disc A is very much reduced, as the disc is accurately fitted on its spindle, and the bearing surface for the rings D, as well as the sides of the case, are carefully turned so that the arms fit, but without actual contact.

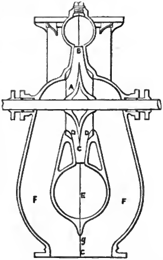
4115.



4117.

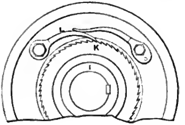


4116.

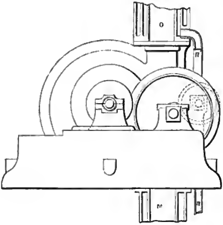


Figs. 4117, 4118, illustrate the second part of this invention, namely, an improved description of frictional gearing for driving centrifugal pumps or other machinery. Fig. 4117 is a cross-section of two wheels, or wheel and pinion, fitted according to this invention. In this case the larger wheel H has a projection *h* formed upon the periphery fitting into a recess of similar shape in the smaller wheel, or pinion, I I^1. This pinion is made in two parts or halves; one half, I, is cast solid with the boss of the pinion, this boss being turned on its outer side to receive the other half of the pinion I^1, which is accurately bored to fit the boss; the shoulder *i* is also turned to fit the recess formed upon the other half, I, of the pinion to give greater steadiness. This pinion is carried on

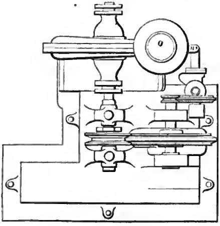
4118.



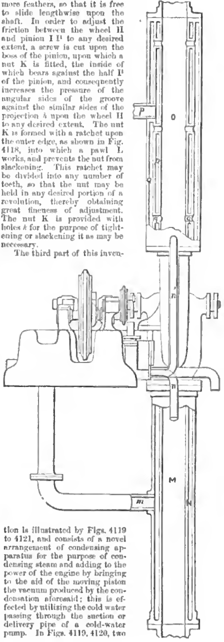
4120.



4121.



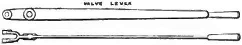
4119.



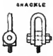
the shaft by means of one or more feathers, so that it is free to slide lengthwise upon the shaft. In order to adjust the friction between the wheel H and pinion I I¹ to any desired extent, a screw is cut upon the boss of the pinion, upon which a nut K is fitted, the inside of which bears against the half I¹ of the pinion, and consequently increases the pressure of the angular sides of the groove against the similar sides of the projection *h* upon the wheel H to any desired extent. The nut K is formed with a ratchet upon the outer edge, as shown in Fig. 4118, into which a pawl L works, and prevents the nut from slackening. This ratchet may be divided into any number of teeth, so that the nut may be held in any desired portion of a revolution, thereby obtaining great fineness of adjustment. The nut K is provided with holes *k* for the purpose of tightening or slackening it as may be necessary.

The third part of this invention is illustrated by Figs. 4119 to 4121, and consists of a novel arrangement of condensing apparatus for the purpose of condensing steam and adding to the power of the engine by bringing to the aid of the moving piston the vacuum produced by the condensation aforesaid; this is effected by utilizing the cold water passing through the suction or delivery pipe of a cold-water pump. In Figs. 4119, 4120, two

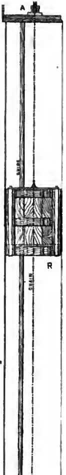
4129.



4130.

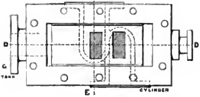


4122.



4127.

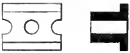
PLAN



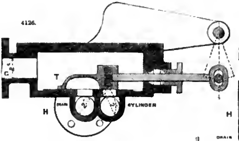
SLIDE VALVE AND CHEST

4128.

PISTON ROD GUIDE

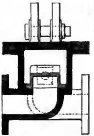


4126.



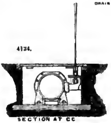
SECTION AT DD

4125.



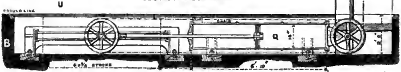
SECTION AT EE

4124.



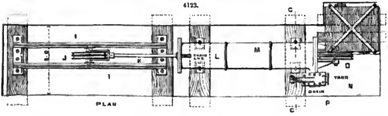
SECTION AT CC

4122.



SECTIONAL ELEVATION

4123.



PLAN

methods of accomplishing the foregoing objects are illustrated. One of these methods consists in forming the suction-pipe of thin copper or other rapid heat-conducting metal or material for a portion of its length at M, immediately outside which another pipe or casing N is placed so much larger than the inner one M as to leave a steam space between them. The pipes are connected together so as to form a steam-tight chamber. The exhaust-steam pipe *m* from the steam-engine or from any vessel from which the steam to be condensed has to be discharged communicates with this chamber, which is kept constantly cold by the rapid circulation of the water passing through the suction-pipe M, and the steam is thereby condensed. An air-pump communicates with the chamber in this instance by means of the pipe *n*, as shown in section in Fig. 4120, for the purpose of working the condenser in the usual way. When the casing is placed sufficiently above the water level to enable the condensed water in the casing to overcome the force of gravity, or, say, more than 27 ft. of fall or height of column, the air-pump may be dispensed with, as the water will run away by its own gravity.

Another mode of applying this invention is shown at O, Figs. 4119, 4120. In this case the condenser is fitted to the delivery-pipe of the pump instead of to the suction-pipe as before, and illustrates a method of obtaining an increase of the condensing surface in a convenient way, and thereby shortening the length of pipe required for this purpose. The delivery-pipe O has two casings or pipes P Q fitted around it in a similar manner to that just described with respect to each other. To the inner chamber P the exhaust-steam pipe *p* communicates, while the water in the delivery-pipe O is permitted to circulate freely in the outer chamber Q through the openings *q*. By this means both the inside and outside of the exhaust-chamber P is cooled by the water raised by the pump and discharged therefrom, and consequently the condenser may be made much shorter. The air-pump is in this case worked similarly to that above described, through the pump a^1. This double casing may be applied to the suction-pipe of a pump, and similarly the single casing may be applied to the delivery-pipe of a pump should it be preferred or found more convenient.

Hydraulic Lift of Alfred Davis, Phœnix Foundry, Derby.—The annexed illustrations, Figs. 4122 to 4130, show a very simple and effective form of hydraulic lift, designed and constructed by Alfred Davis, of the firm of Stacey and Davis. This hydraulic lift has been working for some time, and continues to work, in a most satisfactory manner.

The cylinder is fixed horizontally, and the stroke multiplied by means of pulleys, which at one end revolve in a bracket cast upon cylinder cover, and at the other work in a cast-iron cross-head, keyed to the piston-rod, and guided upon either side.

A chain is led round the pulleys running longitudinally over and under the cylinder, and after passing over the wheel A at the top of shaft, descends to the cage. The supply is drawn from a tank, and is admitted to the cylinder by means of a slide-valve worked with an ordinary lever, which serves the purpose of lifting, lowering, and regulating the speed of the cage.

This lift is single-acting, water being admitted on one side of the piston only: the weight of the cage being made sufficient to accomplish the down stroke. The water, having done duty in the cylinder, is allowed either to flow into the drain or run into a low-level tank to be used for other purposes.

The entire apparatus, with the exception of the cage and its immediate appendages, is enclosed and fixed in a trench below the ground level, and completely boarded over, so that space available for other purposes may not be lost; at the same time, care has been taken that every part shall be easy of access should the parts require inspection.

B, U, Q, F, R, A, Fig. 4122, is a sectional elevation. Q, piston; R, cage, of Davis' hydraulic lift.

I, J, K, L, M, Fig. 4123, is a plan. I, cross-head guide; J, pulleys; K, piston-rod; L, chain lug; M, cylinder.

Fig. 4124 is a section at C C of Fig. 4123.

H, Fig. 4125, is a section at E E of Fig. 4127. H, low-level tank or drain.

G, H, I, Fig. 4126, is a section at D D of Fig. 4127. G, supply tank; H, low-level tank or drain; I, slide-valve.

G, S, Fig. 4127, is a plan. G, supply tank; S, drain or low-level tank.

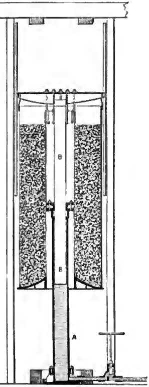
Fig. 4128 is of the piston-rod guide.

Fig. 4129 is of the valve-lever.

Fig. 4130 is of the shackle.

Armstrong's method of transmitting power by water pressure. Taken from the Proceedings Inst. M. E., 1868.—The most distinctive feature in this mode of transmitting power is the apparatus termed the *accumulator*, shown in Fig. 4131, which is so named because it accumulates the power exerted by the engine in charging it. It consists of a large cast-iron cylinder A, fitted with a plunger B, from which a loaded weight-case C C is suspended, to give pressure to the water pumped in by the engine. The accumulator is in fact a reservoir giving pressure by load instead of by elevation; and its purpose is to equalize the strain upon the engine in cases where the quantity of power to be supplied is subject to great and sudden variations. The load upon the plunger of the accumulator is generally such as to produce a pressure equal to that of a column of water 1500 ft. high, and the capacity of the cylinder is sufficient to contain the largest quantity of water which can be drawn from it at once by the simultaneous action of all the machines in connection with it. The accumulator also serves as a regulator to the engine, for when the plunger rises to a certain height it begins to close a throttle-valve in the steam-pipe, so as gradually to lessen the speed of the engine until the descent of the loaded plunger again calls for an increased production of power. From the accumulator the water is conveyed by a pipe to the various places where motive power is required; and in some cases where water is scarce it is returned by another pipe from the machines to the pumping engine to be again forced into the accumulator. The water thus acts merely as a carrier of power, and its function is consequently the same as that of shafting used for conveying the power of a steam-engine to different parts of an establishment.

4131.



The question therefore to be considered is, in what respect or under what circumstances water pressure is superior to shafting for the transmission of power. It is not to be supposed that water pressure would be applicable as a substitute for shafting in mills and workshops where the machines to be driven are compactly grouped at short distances from the engine, and where they are generally continuous in their action. The superiority of water pressure is only realized in those instances where the machines to be put in motion are scattered over a wide area and are intermittent in their action, and also where the quantity of power to be transmitted is subject to great and abrupt variations. Upon an extended wharf, for example, every crane may happen to be in action at one moment, while at another time not one may be moving; and if shafting were used in such a case for conveying power to the cranes, the engine would sometimes be overtaxed and sometimes acting without any useful effect. But with water pressure as the medium of transmission, the variation of work is met by the accumulator; and the engine acts always under a uniform load, storing up its surplus power at times when the whole is not transmitted. Moreover, the ramifications readily carried out in laying water-pipes are not practicable with shafting, nor can shafting be extended beyond very limited distances.

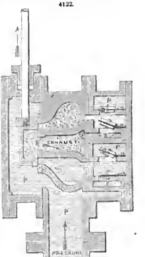
Water pressure also possesses the advantage of communicating to machinery a much more controllable and adjustable motion than shafting. The water can be gradually turned on or shut off, and can be admitted as quickly or as slowly as may be desired; while with a shaft the motion acquired is sudden and cannot be communicated gradually. Another advantage of the hydraulic system is that the pipe conveying the water is itself at rest, and does not suffer any appreciable wear nor require any attention; whereas a shaft being in motion is attended with friction and consequent wear, and involves constant lubrication.

The absence of elasticity in water gives great steadiness and precision to the movements of machines actuated by water pressure; but on the other hand, water being incapable of expanding like steam in a cylinder, the quantity expended is not proportionate to the load. Thus a machine propelled by hydraulic pressure measures off the same quantity of water, whatever may be the resistance overcome; and therefore when the machine is inadequately loaded the expenditure is more than equivalent to the effect produced. This loss of power may in a great measure be obviated by making the machines with variable powers; but the simplicity of single-power machines renders them preferable in many cases, notwithstanding their greater expenditure of power. In fact, for the purposes to which water pressure is most usually applied, safety, simplicity, and general convenience are more to be considered than economy of power, because owing to the intermittent character of the work the required quantity of power is not large in the aggregate. It has also to be recollected that, although power is sacrificed by that very property in water which gives so much steadiness and safety to its action, yet the favourable condition under which a steam-engine works when pumping against a constant head, as in charging an accumulator, cheapens the production of the power, and compensates for its more lavish application.

In connection with the non-elastic character of water, it will be observed that its incompressibility in the cylinder of the machines would, if not provided against, cause very injurious shocks and strains to the machinery, by suddenly arresting the momentum of the moving parts on the closing of the outlet passages. To obviate this liability, nearly all varieties of water-pressure machines adapted for rapid action require the introduction of what are termed relief valves. These will be fully described in our article on *Valves;* and it is therefore only necessary on this occasion to describe them as consisting of small clacks D D, as shown in Fig. 4132, opening against the pressure P in the supply-pipes, and yielding to any back pressure on the piston that exceeds the accumulator pressure. In the drawing P P represents the pressure, and E E the exhaust-passages.

With a pressure equal to a column of water 1500 ft. high, the loss of head by friction in the pipes forms a very inconsiderable deduction from the entire column; and the pressure may therefore be conveyed without any serious sacrifice to great distances from the engine. In some instances the length of the pressure pipes has been extended to more than two miles without any apparent decrease of effect; but in all cases where the pipe is very long it is desirable to apply an accumulator at each extremity, in order to charge the pipe from both ends. The most advantageous pressure of water for practical use seems to be that mentioned above, namely, 1500 ft. or about 700 lbs. a square inch. By increasing the pressure the size of the pipes and of all parts of the apparatus is lessened; but on exceeding the above limit a difficulty begins to be felt in preventing leakage and keeping the valves and packings in order; and this objection more than counterbalances the advantage of reducing the size of the apparatus.

4132.



Compressed air has often been proposed, and in some instances tried, as a medium for the transmission of power. Being elastic it has an advantage over water in accommodating its volume and consequently its expenditure to the load on the piston; but on the other hand it does not give back all the power put into it by the engine, because practically it cannot be used expansively to the full extent of its previous compression. In order to return all its acquired power, the air must undergo no throttling, and must be discharged from the cylinder in which it acts at the density of the atmosphere; and as these conditions are impracticable, the loss from elasticity in air is probably as great as that from the absence of elasticity in water. But the use of compressed air is subject to a far more serious source of waste by leakage, which in the case of air is very difficult to detect; and in an extended system of pipes and machines, requiring a multitude of joints, valves, and fitting surfaces, the leakage of the air must form an insurmountable difficulty. Moreover, the elasticity of air deprives the machines to which it is applied of that perfect steadiness and precision which is afforded by the incompressibility of water. Nor is any advantage to be gained by adopting the converse process of exhausting the air instead of compressing it, since the difficulties which apply to the one case are equally incident to the other.

The purposes to which water pressure has been applied as a means of transmitting power are numerous; in fact in almost every case where manual labour is used as a mere motive power, it may be superseded by engine power transmitted by means of water pressure. The widest application of this system is in docks, where the water-pressure machinery is now most extensively used in England for the purpose of opening and closing the gates, swing bridges, and sluices, and also for hauling ships through the locks and discharging and warehousing cargoes. It is also very generally employed in the various operations connected with the shipment and discharge of coal; and the mechanical arrangements applied to meet the different conditions under which these operations have to be performed are very various, and in some cases necessarily very elaborate. Perhaps the case of greatest novelty in this branch of the application of water pressure is that of a machine erected for the purpose of shipping coals at Goole Docks, on the river Humber, where barges containing 32 tons of coal are floated into a cradle, and then lifted bodily to a considerable height and turned over into a shoot, which delivers the coal into a ship alongside.

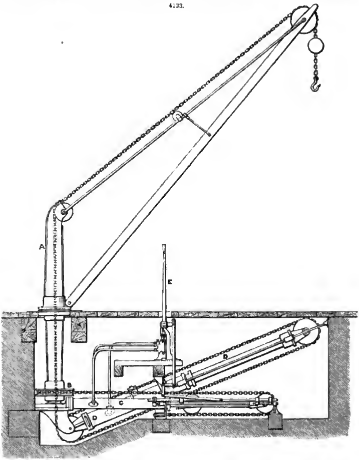
In France it is in use at Marseilles, at Rouen, and at the goods station of the Paris and Lyons Railway in Paris, for the purpose of loading and unloading the wagons, and also for hauling them in the station yard. The machinery at this station affords a good example of the application of the principle to railway goods traffic, and may therefore be selected for description.

The machines comprise fifteen single-power hydraulic platform cranes to lift 1½ ton; and three double-power similar cranes to lift 1½ ton with the lower power, and 3 tons with the higher power; also two hydraulic engines for driving capstan-heads for hauling trucks.

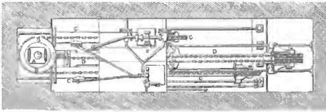
The single-power cranes are represented in Figs. 4133, 4134. They are adapted to turn as well as to lift and lower by the water pressure. The jib is a fixture to the crane-pillar A, which is made to revolve by means of a chain passing round the cupped wheel B, and worked by a pair of hydraulic presses C C. The diameter of the ram of each turning press C is 4 in., and the length of stroke is 3 ft. 8 in., which is doubled by passing the chain over a pulley at the end of the ram and fixing the extremity to the cylinder. The ram of the lifting press D is 5¾ in. diameter, and has a stroke of 4 ft. 8 in., and the motion is multiplied four times by means of pulleys. The chain is conveyed upwards through the centre of the pillar A, and thence over the end of the jib. The lifting cylinder D is placed at an angle, to facilitate the overhauling of the chain. The valves for lifting, and lowering, and for turning, are slide-valves, the lifting and lowering valve having two ports, and the turning valve three ports. Each valve is worked by a lever E passing through the platform, the two levers being placed at a proper distance apart, so as to be worked by a man standing between them with a hand on each lever. To provide against the crane-jib slewing round beyond the range of the turning presses, the turning valve is made to close by a self-acting arrangement at each extremity of the range.

The double-power crane is of the same general construction as the single-power; but instead of a simple hydraulic press with ram for lifting, a bored cylinder with a combined ram and piston is applied, as shown in Figs. 4135, 4136. For the lower power the pressure is admitted upon both sides of the piston A, and therefore virtually acts only upon the ram B, which is half the area of the piston. For the higher power the front side of the piston is open to the exhaust E, leaving the pressure P to act on the back only, and the effect is then proportionate to the area of the piston, which is twice that of the ram. This alternative action is determined by the intervention of an extra valve C, Figs. 4135 and 4137; when this valve is opened, as shown in Fig. 4137, the pressure

4133.



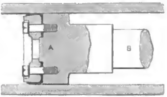
4134.



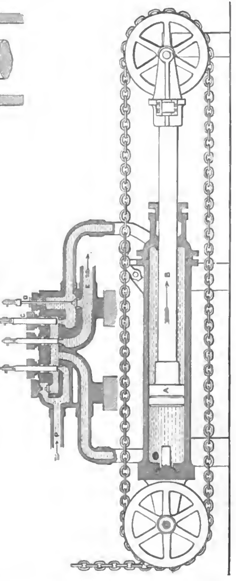
P has access to both sides of the piston, and the lower power is then obtained; while for the higher power the valve C is closed, and the exhaust-valve D is opened, whereby the front side of the piston is kept constantly open to the exhaust E. In cases where three powers are required, three

simple hydraulic presses are commonly used, which act either singly or in combination; but the same effect may be obtained with a bored cylinder and piston combined with two concentric rams,

4136.



4135.



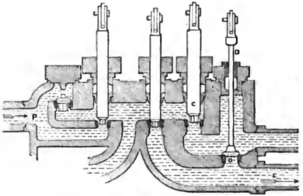
the external ram being secured by a pawl when its action is not required, and the internal ram acting through a water-tight gland in the outer ram. In this case the lowest power is obtained by admitting the water only on the front side of the piston, whence it enters into the interior of the larger ram through a hole near the piston, and forces out the inner or smaller ram. The second power is obtained by admitting the water to both sides of the piston; and the highest power is brought into action by opening the front side of the piston to the exhaust, while the pressure operates on the back of the piston.

The capstan engines used at this railway station have each two oscillating cylinders with combined rams and pistons, working cranks at right angles; on the front side of the piston, which is half the entire area, the pressure is constant, and the back communicates alternately with the pressure and the exhaust. The engine therefore acts by a difference of pressure in one direction, and by a positive pressure in the other, the effective pressure being equal in both cases; and the action is governed by a two-port slide-valve worked direct from the trunnion. In these engines, as well as in the cranes, relief valves are applied to prevent concussion from the water shut in.

Since the platform cranes of the Paris and Lyons Railway were constructed, a new arrangement of platform crane has been introduced, in which the lifting cylinder is arranged so as to form the crane-pillar. An example of this kind of crane is shown in Fig. 4138, where A is the lifting ram acting upon a chain B, which gives a twofold motion to a double-pulley running block C. A corresponding double-pulley block D is fixed to the base of the jib, and over these pulleys the lifting chain passes four times, so that the range of the ram is multiplied altogether eight times at the outer end of the chain.

Another modification of the same kind of arrangement is exhibited in Figs. 4139, 4140, where the crane-pillar is carried in top and bottom bearings, and the lifting press A is placed between the two cheeks of the pillar. In this case there is no turning power, and the lifting valve B, as well as the press, is attached to the crane-pillar, as shown to a larger scale in the section, Fig. 4141.

4137.

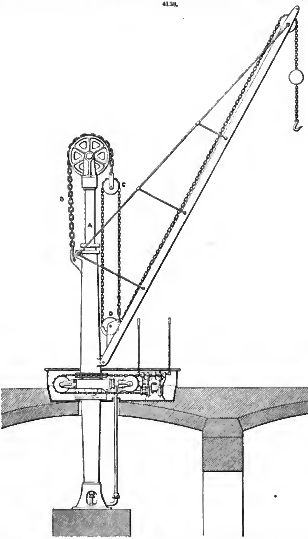


This is the simplest and cheapest form of hydraulic crane which is made. In all cases of cranes containing the lifting press in the pillar, the water is admitted through the pivot at the bottom, which is made water-tight by means of a cupped leather. For cranes of a very high power, where only slow motions are required, it is now usual to employ the ordinary gearing of a steam-crane, and to apply the water pressure by means of a small hydraulic engine fixed in the framework of the crane.

Hydraulic cranes have of late years been introduced with great advantage at the Elswick Works, both in the forge and in the foundry. In the forge they are applied to the service of a 12-ton hammer, and by this means forgings ranging in weight up to 20 tons are manipulated under the hammer with perfect precision and great saving of time and labour. In the foundry they are so applied as to command every part of the floor, and thus wholly to supersede manual labour for every purpose of lifting and carrying. The form of crane used in each of these departments is the same, and is represented in Figs. 4142, 4143. The jib and pillar of the crane are of wrought iron, and revolve in top and bottom bearings. The crane has three motions, namely, lifting, turning, and traversing, all of which are effected by hydraulic power. The lifting cylinder A is made of double power by the ram and piston arrangement before described, the highest power being equal to 20 tons; the ram is 11 in. diameter, and the piston 15¼ in. diameter, the length of stroke being 6 ft. 8 in. The turning cylinders B are applied in the usual manner at the foot of the crane-pillar, the rams being each 4½ in. diameter, with 5-ft. stroke; and both the lifting and the turning cylinders, with their valves, are fixed in a chamber beneath the level of the floor. A three-port slide-valve is used for the two turning cylinders, and mitre-valves for the lifting cylinder. The chain from the lifting cylinder is carried upwards through the crane-pillar, bending over a sheave C at the top of the pillar, and passes successively over the pulleys of the travelling carriage D and the running block E, and is finally made fast at the extremity F of the jib. For the purpose of overhauling the ram of the lifting press, a small press is placed between the two turning presses B; and the overhauling action is effected by a chain and sheaves multiplying four times, the outer end of the chain being attached to the sliding head of the lifting ram at I. The pressure in the overhauling press is constant, and its action is therefore equivalent to that of a counterweight; the ram is 4½ in. diameter, with 3 ft. 5 in. stroke. For effecting the traversing motion of the load suspended at the hook G, the travelling carriage D is hauled inwards and outwards by two presses H fixed to the back of the crane-pillar, and connected by chains with the travelling carriage; the ram of each press is 5½ in. diameter, with 4 ft. 7 in. stroke. The alternating action of these presses, which is precisely the same as that of the presses B used for the turning motion, is regulated by a three-port slide-valve K attached to the front of the pillar, with a lever at each side for working it. The water is supplied to, and discharged from, these presses by two pipes which pass through the top bearing of the pillar, and the connection between the valve and these pipes is effected in each case by a trunnion joint at J J.

Another novel purpose to which hydraulic pressure has recently been applied is the raising of the materials required for feeding blast furnaces. The great increase in the height, size, and productive power of modern blast furnaces has necessitated a great increase of speed and power in the lift; and the employment of water-pressure machines has fully satisfied these requirements. The apparatus employed for this purpose is represented in Fig. 4144. The framework of the hoist is constructed of cast iron columns supported by wrought-iron bracing. Two guided cages A A are used for receiving the barrows containing the materials to be raised to the furnace mouth; and two separate lifting-presses B B, one for each cage, are fixed in an inverted position against opposite sides of the framing, the ram of each press being 11½ in. diameter with a stroke of 8 ft. The lifting chain makes five turns over the pulleys C C of each press, so as to multiply the stroke tenfold, and is carried up over a sheave D at the top of the framing, and thence descends to the cage to which it is attached. The two cages are connected with each other by a wire rope which passes over a sheave E at the top of the framework, so that they balance each other, the one being lowered

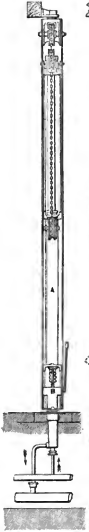
4138.



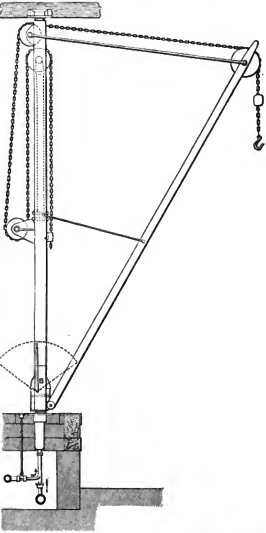
while the other is raised. The cages lift two barrows at a time, weighing with their contents 1½ ton, and they are hoisted to the top at the rate of 4 ft. a second; a much higher speed could be attained by increasing the size of the valves and pipes to the required extent. A three-port slide-valve is used for working the two presses, and admits the water to the one press while it discharges it from the other. The valve is worked at the bottom, but a rope is provided to enable it to be worked from the top as well. An arrangement is applied by which the cages gradually close the valve at the termination of each lift, and thereby ensure a soft and gradual cessation of the motion; and a safety apparatus is attached to each cage, to arrest its fall by gripping the guide bars in the event of the breakage of a chain.

When this paper was read, R. Mallet observed that it was a remarkable circumstance that Bramah, the inventor of the hydraulic press, had suggested as early as 1802 the application of the

4139.

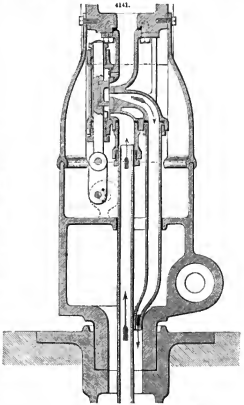


4140.



same principle for working the cranes on the dock quays at Dublin and in the warehouses of the London Docks, as was shown by the accompanying autograph letter. Extract from autograph letter of Joseph Bramah to Robert Mallet, dated London, 10th Nov. 1802, the original of which was shown to the meeting;—"I have also now applied it" (the hydraulic press) "with the most surprising effect to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device, that I will engage to erect a steam-engine in any part of Dublin, and from it convey motion and power to all the cranes on the keys and elsewhere, by which goods of any weight may be raised at one-third of the usual cost. This I do by the simple communication of a pipe, just the same as I should do to supply such premises with water. I have a crane on my own premises which astonishes every person to whom it has been shown, as they see the goods ascend and descend fifteen or twenty times in a minute to the height of 18 or 20 ft., and at the same time it is impossible for any person unacquainted with the principle to discover how or where the power comes from." This shewed that Bramah had distinctly seen the great scope for future expansion of the principle; but he had been too much in advance of the time for his ideas to be practically developed during his lifetime to so great an extent as they had since been by the very ingenious and perfect arrangements of Sir Wm. Armstrong described in the paper now read.

4141.



Hydraulic Rams.—The hydraulic ram, the principle and mode of action of which every engineer is acquainted with, is employed solely for the purpose of raising water. See Fig. 93, p. 35. It may therefore be classed among pumps; but as it utilizes for this purpose a volume of water falling from a certain height, that is, a fall of water, it must also be considered as a *hydraulic motor*.

We shall not describe here the classic ram of Montgolfier, with which everybody is acquainted; but we will at once examine the improved ram by M. Bolée, of Le Mans, which was exhibited in Paris in 1867. This ram, represented as a whole and in detail in Figs. 4145 to 4153, is nothing but Montgolfier's ram provided with certain details which give it a regular and permanent action and enable it to work without being constantly attended to.

The motive water arrives through the pipe A, and the water raised is forced into the reservoir of air D, whence it flows up the ascension-pipe. When the ram is not at work, the valve B is let down; it would allow a passage to the water if care were not taken to place a hatch at the head of the conduit which brings the water to the body A of the ram. Suppose this hatch opened, the water puts itself in motion in the conduit, and the ram begins its action, presenting successively and periodically the three following phases;—

First phase.—The water that arrives through the inlet-pipe begins to flow with a velocity due to the height of the fall, through the valve B (which is let down), and through the spaces between the four arms *t* of the upper guide of this valve, Fig. 4148; but the flow of the water and the pressure exerted by it while in motion upon the lower face of the valve, causes this latter to close, and the issue of the water ceases.

Second phase.—At the moment when the issue of the water ceases, the *vis viva* possessed by the column of water in motion causes the *ramming stroke*, that is, opens the retaining (or forcing) valve G; the water enters the air-vessel D, and at the same time, in consequence of the effect of the shock upon the valve G, and in virtue of its elasticity, flows back through A.

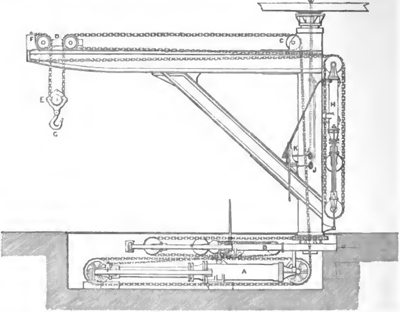
Third phase.—At the moment when the backward motion begins, the valve G closes and B opens, again allowing a passage to the water coming from the upper water-course; then the three phases begin over again.

Having explained the action of the ram, we have only to describe the details of its construction.

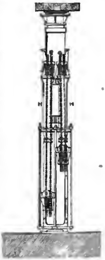
The valve B is partly balanced by a counterpoise *c*, to which it is connected by means of a rod *b*. The effect of this addition, which does not exist in Montgolfier's ram, is to make the valve B close more readily. The lower rod of this valve is guided, as shown in Fig. 4148, in a little cylinder with two lateral openings, the bottom of which is furnished with india-rubber washers. Consequently the valve on falling strikes easily and noiselessly against its lower stop.

To ensure the proper action of the ram, and to prevent a breakage either in the inlet or in the outlet pipes, an indispensable condition is that the reservoir D constantly contain a sufficient quantity of air. But in Montgolfier's common ram the reservoir is supplied by a *snifting valve* placed upon the body of the ram: the consequence of this is that in wet seasons the water rises above this valve, and as the supply of air is cut off, there is danger of a breakage occurring.

4142.



4143.



This defect M. Boléo has removed in the following way;—In front of the valve B he places a long, vertical, hollow column *e*, Figs. 4145, 4146, the top of which is high enough to be out of the reach of the highest floods. The details of the head of this column are shown in Fig. 4151. It is furnished with a snifting valve, the opening of which is regulated by the pointed screw *m* and a retaining valve *s*; a pipe *e'* forms the communication between the chamber of this valve and the body of the ram; the pipe opens into the ram below the clack G at E', Fig. 4145, and its orifice is furnished with a second valve *s'*, the details of which are shown in Figs. 4152, 4153. At the moment when the stroke occurs below the valve G, the water ascends violently the column *e* and compresses the air contained in it; a portion of this air escapes through the snifting valve, but the remaining portion lifts the valve *s*, and occupies a position above.

When the valve B descends, and the water entering the ram flows through the orifices of this valve, the water descends in the column *e*, and the external air enters through the snifting valve. The valve *s'* prevents the compressed air surrounding it from returning into the pipe *e'*, by closing the orifice of this pipe under the action of the stroke. The compressed air contained in the chamber of this valve is then forced to enter under the clapper G at the moment when the latter is open, and this air rises up into the air-vessel D. Thus the supply of air to this vessel is effected at each stroke.

It is obvious that the importance of the mass of water contained in the ram, from the commencement of the inlet-pipe up to the clapper G, is not unworthy of consideration from the point of view of the effect produced. No authoritative rule exists relative to this question. According to some writers, the length of the body of the ram, that is, the length of the inlet-pipe, should be about ⅔ of the height to which the water is to be raised. According to others, this length should be equal to the height, increased by the ratio between the double of the height and that of the fall. But neither of these empirical rules are in accordance with the dimensions of various existing rams.

As a mean, it may be reckoned that in a well-constructed hydraulic ram, the work, that is, the proportion of effective work in water raised to the motive work expended, is 60 per cent. This is a result that is not easily obtained with the best hydraulic motor working the best system of pumps. But the hydraulic ram can be constructed for only very small forces: were it not for this fact, this very simple engine would be generally employed.

Leblanc's Ram.—We will conclude our remarks on hydraulic rams with a few words respecting a contrivance employed to draw water from an excavation.

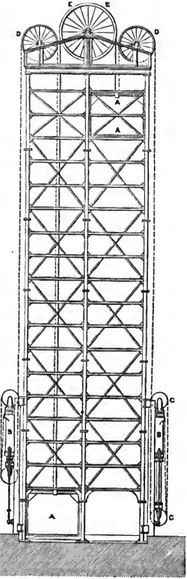
When the quantity of water to be drawn up is small, it is well to utilize the fall itself upon which hydraulic works are executed to effect the clearing of the excavation.

Fig. 4154 represents a hydraulic ram contrived for emptying a place of water. Two valves S S are connected by a beam oscillating about an axis *o o*. The water of the upper course, by flowing through the aperture uncovered by one of the valves, produces the effect of the water-spout, and sucks up the water from the stream to be emptied through the pipe *n n*. This pipe is provided with an air-vessel *m*, and separates into two branches S′ S′, furnished with retaining valves; each of these two branches opens under the seat of one of the valves S S. The water sucked up flows away into the lower course, with the motive water, through one of the pipes *d d*. The flow of the motive water through one of the valves S causes this valve to close, and consequently the other to open, and *vice versâ*. Thus the apparatus is self-acting.

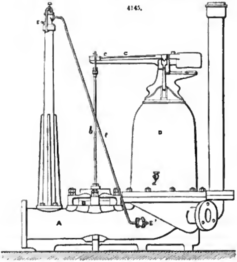
The hydraulic ram was used in making the Mont Cenis tunnel to compress the air necessary for the supply of the wind-ways and for working the boring tools. Before the erection of the powerful compression-pumps used later, M. Sommalier, the engineer of these works, had a series of hydraulic rams constructed working under a fall of 26 mètres. These rams compressed up to five atmospheres the air necessary to drive the tools and to ventilate the works.

Water-pressure Engines.—This class of motors is generally erected to utilize small volumes of water and very high falls. They are usually employed to raise water or rather to drive pumps. In this case it consists, in its essential parts, of a cylinder and a piston moving with a reciprocating motion; the piston-rod transmits this motion directly to the pump. It will be seen at once that the construction of water-pressure, or as they are usually called, reciprocating engines, is much more like that of steam-engines than that of the hydraulic motors which we have already considered. These pressure engines, however, require a particular arrangement of the distributing apparatus, often giving occasion for some very ingenious and remarkable contrivances, which we will describe farther on. Two artifices used to vary the pressure in a steam-engine, namely, *expansion* and *variation of pressure*, cannot be employed in a water-pressure engine. The water being incompressible cannot expand, and if the pressure were made to vary, the utilized fall would be diminished without proportionately reducing the volume of water expended (which is always equal to the volume generated by the piston); therefore the duty of the engine would be decreased, which would be bad. The variations of the fall, and consequently of the pressure, should be only an inappreciable fraction, so to speak, of the total fall; for this reason, these engines are applied only to high falls.

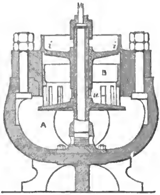
4144.



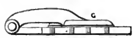
4145.



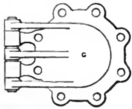
4148.



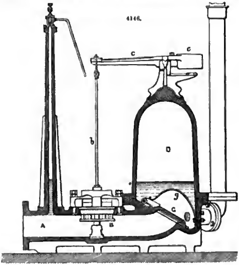
4149.



4150.



4146.



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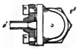

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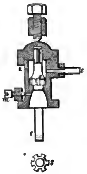

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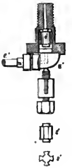

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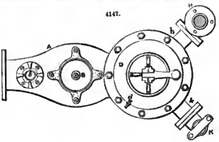
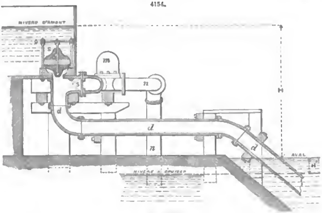
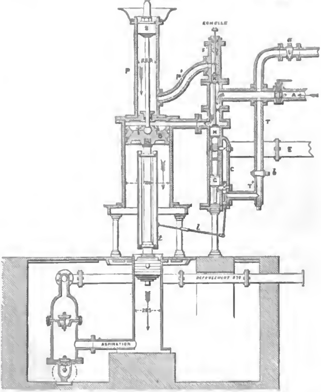


M. Girard has, indeed, studied their application to low falls, but the motion has not been received in practice.

4154.



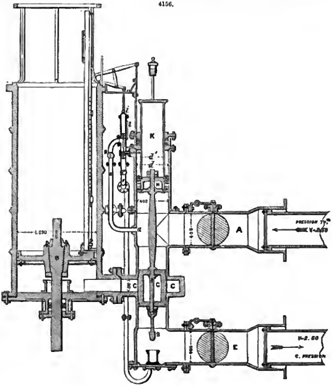
4155.



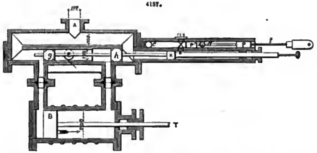
With respect to the mode of action of the water, these engines are divided into two classes: single-action and double-action engines; the former are vertical, the latter horizontal. Direct and single-action reciprocating engines work either with a downward or with an upward stroke. In the former case, the motive water is let in only upon the upper face of the piston; in the latter case, it is let in only beneath its lower face.

Reichenbach's engine at Ilsang, in Bavaria, is the oldest and most remarkable type of the single-action engines, working with a downward stroke. Fig. 4155 represents a vertical section of this engine. For the sake of brevity, we will merely give an explanation of the references.

4156.

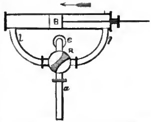


4157.



A, the inlet-pipe; a valve *o* serves to regulate the speed of the engine, that is, the expenditure of water. This expedient is serviceable where there is an excess of fall, but it is bad in principle, as the partial closing of the valve causes a contraction. *a*, air purge-cock; when this is opened before the engine is started, the cock *b* is shut, and when the engine is cleared of air, the cock *a* is closed and *b* opened. E, outlet or discharge pipe for the water that has done its work; in the figure, the communication between this pipe and the cylinder is interrupted by the piston H, and the communication between this same pipe and the cylinder C established.

4158.



At starting, the driving or loaded piston B being at the top or beginning of its stroke, the mutually dependent pistons K, G, H, are raised so that the piston H may occupy the position H′. The pistons *p* and *p′* are moved by hand, and the orifice *o* is uncovered to put it in communication with the discharge-pipe E. The diameter of the piston K is a little less than that of the pistons H and G, which are equal, and the top of this piston is in communication with the motive water through a pipe which opens at *o′*. The valve O being open, the pressure of the water causes the three pistons K, H, G, to descend, and the piston H uncovers the orifice of communication with the driving piston B; these three pistons then occupy the positions shown in the figure. As the piston S, which is in constant communication with the motive water through the pipe P′, is of a much smaller diameter than the loaded piston B, the latter descends, and brings down, consequently, the piston *u* of the pump; this piston forces the water to be raised up the ascending pipe.

A little before the piston B has reached the end of its stroke, a pin *t* acts upon a lever *l*, which raises the pistons *p* and *p′*, and places them in such a way that the orifice *o* is put in communication with the pipe T, which brings in the water. The result of this is that as soon as the piston B is at the end of its stroke, the bottom of the piston G is in communication with the water; the pressures upon the pistons G and H therefore balance each other. But as the upper rod of the piston K is a little larger in diameter than its lower rod, the water raises the three pistons and replaces them in their original position. The top of the piston B is in communication with the escape-pipe E, and the pressure under the piston *s* raises this piston, and consequently the loaded piston B, as well as the pump-piston *u*. When the loaded piston has been raised to the position it occupies in the figure, a lower pin *t* has moved the lever *l* to bring down the pistons *p* and *p′*, and make the engine begin again the downward stroke.

The pressure of the water is 116 mètres; the stroke of the pistons B and U is $1^{m}\cdot05$; the engine makes $2\frac{15}{100}$ strokes a minute; and the salt water is raised by the pump to a height of 378 mètres, including the suction; the stroke of the pistons K, H, G, is $0^{m}\cdot330$. The volume of water expended at each double stroke may be resolved thus;—

1. For the downward stroke there is expended a cylinderful for piston B;

$$\frac{\pi}{4} \times \overline{0\cdot720}^2 \times 1^{m}\cdot05 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad 428 \text{ litres.}$$

2. To change the direction of the motion, a cylinderful is expended for piston G;

$$\frac{\pi}{4} \times \overline{0\cdot235}^2 \times 0^{m}\cdot33 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad 10 \text{ litres.}$$

3. To raise the pistons S, T, U, a cylinderful is expended for piston S;

$$\frac{\pi}{4} \times \overline{0\cdot285}^2 \times 1^{m}\cdot05 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad 67 \text{ litres.}$$

4. To change the direction of the motion, that is, to determine the ascent of the three pistons S, T, U, there is expended only the difference between a cylinderful of G and a cylinderful of K;

$$\frac{\pi}{4}\left(\overline{0\cdot235}^2 - \overline{0\cdot195}^2\right) \times 0^{m}\cdot33 = 4\cdot15 \text{ litres, say 5 litres.}$$

The total expenditure of motive water (fresh water) is thus 510 litres, say 500 in round numbers. Motive work in horse-power a second, $\text{M}\, w = \dfrac{500^{k} \times 116^{m} \times 2^{s}\cdot15}{60 \times 75^{kg}} = 28$ horse-power.

The pump U raises at each stroke 67 litres $\left(\frac{\pi}{4} \times \overline{0\cdot285}^2 \times 1^{m}\cdot05 = 67 \text{ litres}\right)$, weighing about 1·20 kilogramme the litre, to a height of 378 mètres. The effective work in horse-power a second is therefore $\text{E}\, w\ \dfrac{80^{k} \times 378^{m} \times 2^{s}\cdot15}{60'' \times 75^{kg}} = 14$ horse-power.

The work *in water raised* is therefore 50 per cent.

These calculations are only approximative, since they suppose that the volume generated by the pistons is just the volume expended or raised, and that there is no loss from escapes.

The engine erected by M. Jüncker at the Huelgoat Mines (Finistère), a vertical section of which is shown in Fig. 4156, is an imitation of Reichenbach's. It is, however, much more powerful and more rigid. The well in which it is fixed, offered only a limited space, and consequently its erection required special arrangements. The pump, too, which it had to work, being situate at a great depth beneath the engine, a long, heavy rod had to be balanced. This last circumstance induced M. Jüncker to make the engine work with an upward stroke only, in order that the rod might be subjected to tension in transmitting to the pump the work requisite to raise the water.

As the Huelgoat engine works only with an upward stroke, the upper part of the cylinder is open, and the leakage of the piston may therefore be readily perceived; this is not the case in Reichenbach's engine.

The adit is situate 14 mètres above the engines, so that the weight of all the tackle is balanced, for the ascent, by a column of water 14 mètres high, having as a base the section of the loaded piston. The introduction and discharge of the water, and consequently the speed of the engine, is regulated by means of the piston G. The figure shows this piston in its middle position; it closes the admission-port C beneath the loaded piston.

The engine is started by opening the cock R, which puts the inlet-pipe A in communication with the space between the two pistons *p*, *p'*, which is of the same diameter; the cock *c* is also open. In order that the pistons *p* and *p'* may be easily brought into the position shown in the figure, that is, so as to uncover the orifice of the pipe o o, which puts the pipe *a* in communication with the top of the piston H, a pipe *t* is made to afford communication between the two faces of the piston *p*; the diameter of the rod *i* of this piston is such that the pressure of the water upon the annular surface of the piston *p* around the rod *i* is exactly equal to the counter-pressure beneath the piston *p'*. The moving hand of the pistons *p* and *p'* puts the two faces of the piston H in communication, and, as the annular surface of the upper face, increased by the section of the piston G, is a little greater than the area of the lower face, the water forces down the whole of the pistons K, H, and G, and opens the port C, through which the water is let under the piston B. The ball *s* at the end of the rod of the piston G enters a small cylinder *v* bored to a diameter only a very little greater than that of the ball; the water in this cylinder breaks the descent of the parts and prevents a shock. When the piston B is near the end of its stroke, a system of pins and levers raises the pistons *p* and *p'*, so as to put the pipe o o in communication with the escape-pipe *e e*. This causes the piston G to ascend, which, passing before the port C, rises above, to put the lower face of the piston B in communication with the eduction-pipe E. The piston B then descends, and another system of pins brings back the pistons *p* and *p'* to the position shown in the figure, when the piston B has arrived at the end of its stroke.

We ought to remark here that the passage of the distributing piston in front of the port C has the effect of stopping for an instant the loaded piston B when it has reached the ends of its stroke. The dead-points of the pump are in this way very distinctly marked; this is a favourable circumstance, as it allows the valves time to close. This arrangement also causes the piston to start slowly in either direction, which gives the valves time to open fully before the pump-piston has acquired its full speed. The engine may be stopped at any part of its stroke, and the stroke may be varied as required. Thus Jüncker's engine is the most perfect of any at present employed.

Pfetsh's Horizontal, Double-action Engine, erected at the Salt-works of St. Nicholas, at Varangeville.—This engine, a section of which is shown in Fig. 4157, works directly a horizontal double-action pump, by means of the rod *t*. The engine being a double-action one, it has two distributing pistons *g* and *h* (the diameter of the second being a little greater than that of the first), which put successively each face of the piston B in communication with the induction-pipe A and the eduction-pipe E. The distributing pistons are worked as in Jüncker's engine, by means of two small pistons P and P' of equal diameter.

In the position shewn in the figure, the pistons P and P' put the fore face of the piston K in communication with the escape *e*; the distributing pistons *g* and *h* (both on the same rod) are then placed in the position shown in the figure, so that the piston B is about to move in the direction of the arrow. On approaching the end of its stroke, the piston B acts upon the rod *t* and places the pistons P and P' so that the orifices *o* and *a* are comprised between them; the water then presses upon the fore face of the piston K: this causes *g* and *h* to move back so that the fore part of the cylinder is in communication with the pipe A, and the after part in communication with the orifice E of the escape-pipe. The piston B then begins its back stroke, and, having reached the end, it acts upon the rod *t* to bring back the pistons P and P' to the positions they occupy in the figure; this causes *g* and *h* to replace each other, as the figure also shows.

Reciprocating engines have been used during the last few years to turn a shaft. Since the Exhibition of 1851 they have become common in England, especially among the lead mines of the North, where they are used to raise the ore. Sir Wm. Armstrong is the chief constructor of this kind of double-action engine, which he employs to work whims. They consist, in their essential parts, of two horizontal cylinders, the pistons of which drive two cranks at right angles. A distributing apparatus comprising, for each cylinder, a *normal* slide-valve, that is, without lead or overlap, which must be regulated with great nicety on account of the incompressibility of the water. These engines have between the diameter and the stroke of the pistons the usual proportions of a water-pump, and they work at a low rate of speed, generally less than twenty revolutions a minute. The induction-pipe should be provided with the necessary means for avoiding ram strokes, namely, an air-vessel, or safety-valves, or a plunger loaded with weights and moving in a pump-barrel fixed near the engine and in communication with the induction-pipe. The motion of the slide-valves is communicated by means of link-motion, which enables the engine to be reversed, so as to drive the whim sometimes in one direction and sometimes in the other. If the reversing is not required, the distribution may be effected by a three-way cock R, Fig. 4158. In the position shown in the figure, the port *l* is in communication with the inlet *a*; whilst the port *l* is in communication with the escape *e*, the piston B is moving in the direction of the arrow.

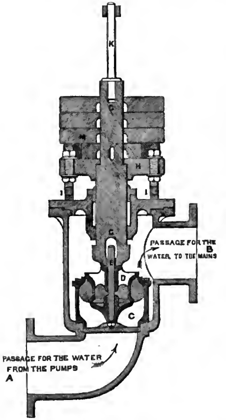
It is indispensable that the water employed in these engines should be quite free from gravel and other bodies in suspension, which would soon injure the rubbing parts.

Sir Wm. Armstrong has also constructed triple engines, with double-action, the three pistons of which drive three cranks conjugated at 120°. As an example, we will cite the 8 horse-power engine at the docks of Marseilles. It has three horizontal oscillating cylinders, and it drives a cranked shaft. The hollow axis of each oscillating cylinder receives the water on one side, and on the other works its slide-valve, which is wholly detached from the cylinder. These cylinders are $0^{m}\cdot107$ in diameter from inside to inside, and the stroke of the pistons is $0^{m}\cdot304$. As the engine makes twenty revolutions a minute, it follows that the mean velocity of the pistons is only $\frac{0^{m}\cdot304 \times 2 \times 20^{r}}{60''} = 0^{m}\cdot203$ a second.

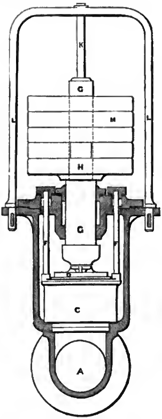
Substitute for a Stand-pipe, invented by Samuel Hocking, C.E., who first applied it to the Croydon Water-works in 1851.—In applying the single-acting Cornish engine to water-works where there is a variable pressure in the mains, a stand-pipe was added to maintain a uniform resistance against the action of the engine.

When the Croydon Water-works was designed by Mr. Ranger in 1850, it was considered that the storage reservoir on the hill was near enough to the engines to serve for the ordinary stand-pipe; and the engines were contracted for accordingly, that is to say, to work without the usual stand-pipe. Subsequently, however, the contractor's engineer, Samuel Hocking, who designed and erected these engines, finding that the town was to be supplied by branch pipes leading off from the main that conveyed the water from the engines to the reservoir, and that any breakage taking place in those branches might so lessen the resistance against the pumps as to endanger the safety of the engines, the entire risk of which was guaranteed by the contractors for one year, he contrived a cheap substitute for the ordinary stand-pipe, which the contractors supplied at their

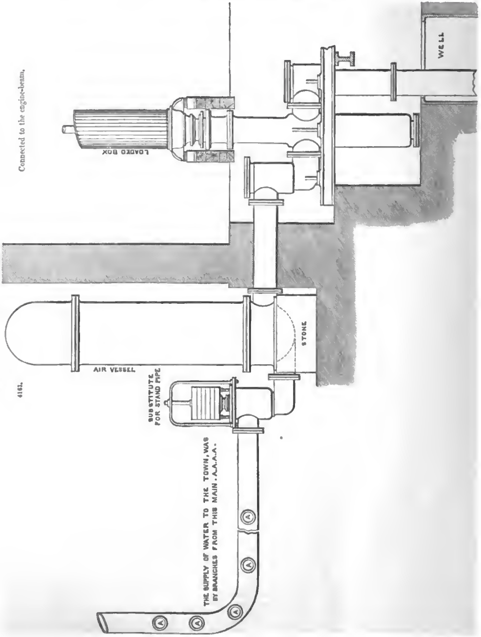
4159.


K
C
M
H
I
I
C
E
D
C
PASSAGE FOR THE WATER TO THE MAINS
B
PASSAGE FOR THE WATER FROM THE PUMPS
A

4160.



A, Branch joining air-vessel. B, Branch joining the main. C, Valve-seat. D, Valve, with small opposing surface to the flow of water through it. E, Valve-spill, fixed to the seat; and to get ample room for the top end of it, there is a hole in the bottom end of the plunger. N.B.—The valve here is free, but it may be hung fast to the plunger. F F, Bolts for fixing the valve-seat. G, Plunger, with a collar to limit its lift. H, Lowermost weight, fixed to the plunger. I I, Legs, to prevent the falling plunger striking hard on the valve. K, Lengthening-piece on top end of plunger. L, Guide for ditto.

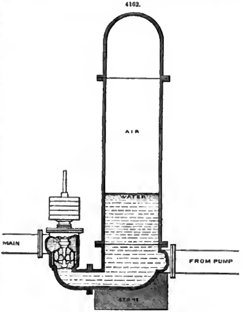

Connected to the engine-beam.
LOADED BOX
WELL
AIR VESSEL
STONE
SUBSTITUTE FOR STAND PIPE
THE SUPPLY OF WATER TO THE TOWN, WAS BY BRANCHES FROM THIS MAIN. A.A.A.A.
A
A
A
A
A

4161.

own cost rather than incur the risk of accident to the engines from that source during their period of guarantee.

This ingenious substitute for a stand-pipe, the construction and application of which we illustrate, Figs. 4159 to 4162, has a valve that is made to shut against the flow of water issuing from the pumps, which valve must open before any water can get into the main. It also has a plunger, or *hydraulic ram*, passing through a stuffing box over the valve; the bottom end of the plunger rests on the valve inside, and the top end of it carries a weight outside the main. The outside end of the plunger is loaded with weights amounting to a little less than that due to the full hydraulic pressure acting against the inside end of it. When the mains are under full pressure, this plunger is lifted up to its limit of travel, and the valve left free to act, nothing bearing on the valve but the pressure due to the column of water confined in the main. Whenever the hydraulic pressure in the mains gets reduced through accident or otherwise, the excess of weight on the plunger will bring it down to bear on the top of the valve, where it will act with that portion of its weight that is not balanced by the diminished hydraulic pressure in the main, thus maintaining a uniform load on the valve, and a uniform resistance against the engines. In starting, the engines have to pump against a weighted valve instead of a given column of water; and when the column is full, the weights cease to act.

4162.



Section of air-vessel, Fig. 4161.

Had a common flat valve been used, the plunger above it would then be of the same diameter, requiring an unwieldy weight; but by reducing the area of the valve exposed to the upward flow of water, after the manner of construction of the ordinary double-beat valve, a small size plunger with manageable weights suffices.

To explain the construction of this apparatus more particularly, reference being made to Figs. 4159, 4160;—

A, that part of the apparatus that is fixed to the engine-pump, and through which all the water pumped has to pass to the valve C D, and thence to the mains through B.

C D, valve-seat and valve of the double-beat kind, the valve D working on a central spindle E.

F F, two bolts for screwing down the valve-seat from outside.

G, plunger-pole or ram, with a collar to prevent its rising too high; and a recess cast in the bottom end of it to give ample length of guide-spill for the valve.

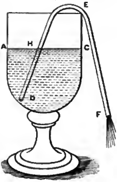
H, a heavy cast-iron block, forming a round table for carrying the weight used for loading the plunger; it is securely fixed to the plunger-pole. It has two adjusting studds as legs, marked I I, on which the weight of the loaded plunger acts, thereby preventing it from striking on the valve, in case of sudden removal of hydraulic pressure by breakage of the mains.

K, wrought-iron lengthening-piece to the cast-iron plunger, over which the cast-iron weights M M slide off and on to adjust the load on the plunger when required.

L, a wrought-iron guide to steady the top end of the plunger-pole.

The beats of the valve C D are made very narrow—less than ¼ of an inch—to prevent the heavy jumping action that would have been occasioned by wide beats; before the valve opens, the force is measured by the surface within the beats, but the instant the valve moves, it is measured by the outside diameters.

4163.

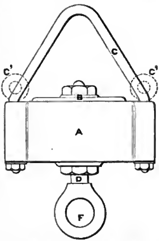


The Siphon.—If one end of a bent tube be put into a vessel of water, Fig. 4163, and the other end without be lower than the surface of the water, then if the air be extracted out of the tube D E F, or the tube be filled with water, the water will flow through the tube in a continued stream, until the surface of the water in the vessel is on a level with the extremity F. For when the air is drawn out of the siphon, the water will rise in it to E by the pressure of the atmosphere upon the surface of the water A C, and then it will descend to F by its own gravity. The siphon being full of water, the forces which act upon the water in the tube are the pressure of the atmosphere upon the surface A C, and the weight of the column of water E F, acting in the direction D E F; and the pressure of the air at F, and the weight of the column of water E H, acting in the opposite direction F E D. The pressure of the air on F and an equal surface of A C, may be considered equal to each other, for the difference of the altitudes of A C and F is too small to produce any appreciable effect on the pressure of the air; these pressures on the tube D E F will therefore balance each other. But the weight of the column of water E F being greater than the weight of the column of water E H, the sum of the pressures in the direction D E F is greater than the sum of the pressures in the direction F E D; the fluid, therefore, will continue to flow in the direction D E F until the surface of the fluid A C is on a level with F.

The siphon will not act if the height H E be greater than 33 ft., for then the pressure of the atmosphere on the surface A H will not be sufficient to raise the water to the highest point E.

Hydraulic Weighing Machine.—This machine, Figs. 4164 to 4166, invented by F. E. Duckham, presents improved appliances and furnishes a means of attachment for the goods to be weighed, whereby they may be suspended from the piston instead of being placed directly upon it; in this manner all liability to press unequally on the piston is avoided, as well as the consequent development of undue friction between the piston and the sides of the cylinder, which frequently occurs when goods are placed on a platform formed by the top surface of the piston. For this purpose the inventor suspends or attaches the apparatus or cylinder by means of a suitable stirrup-piece or sling connected to a link from a crane or in other convenient position. The goods to be weighed are suspended from the centre of the piston by means of a piston-rod which passes through a suitable water-tight gland or packing in the bottom of the cylinder, and to the lower end of which rod the goods to be weighed are attached. A pressure-gauge communicates as usual with the liquid in the cylinder for the purpose of indicating the degree of pressure on such liquid, or in other words the weight of the goods suspended.

4164.



Instead of employing a central piston-rod passing through the bottom of the cylinder, the goods may be suspended by means of an inverted stirrup-piece, similar to that by which the apparatus is sustained, and which is passed over the top of the piston and down through guides placed on the outside of the cylinder, below which it is united in a link, to which the goods may be attached. In this case the top of the piston should be made of sufficient diameter to project slightly over the top of the cylinder.

Instead of suspending the apparatus by means of a sling or stirrup-piece, it may be mounted in gimbals or trunnions supported by a bracket or shelf, or the apparatus may be bolted securely thereto, the goods being attached as previously described.

When this contrivance is employed to denote strains, or for other testing purposes, the cylinder is firmly secured in a vertical or other position, and tension applied to the piston-rod or stirrup-piece, the strain being denoted on the pressure-gauge as before.

4165.

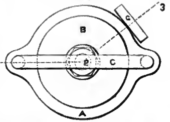
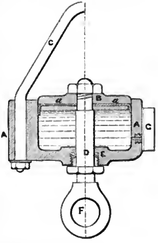


Fig. 4164 is an outside elevation of one arrangement of this hydrostatic weighing apparatus; Fig. 4165 a plan, and Fig. 4166 a sectional elevation taken on line 1, 2, 3, Fig. 4165. A is the cylinder containing water or other suitable liquid, on the surface of which rests a piston or plunger B. To this cylinder A is bolted a stirrup-piece C, by which we may suspend the apparatus from a crane or apply it in any other convenient position. Instead of a stirrup-piece the apparatus may be slung by a chain or chains attached to eye-bolts C¹ C¹, connected to the cylinder. D is the piston-rod passing down through a water-tight gland or packing E in the bottom of the cylinder A. At the lower end of this rod D is formed an eye F, to which the goods to be weighed are attached. The latter are thus suspended from the centre of piston B, on which the pressure will be uniformly distributed. G is a pressure-gauge of any suitable construction, and communicating with the liquid in the cylinder, for the purpose of indicating the weight of the goods suspended from piston-rod D, the connection being either through the back of the gauge, as shown in Fig. 4166, or through the rim of the gauge, or the connection may be at any other convenient point. The piston B and gland E are made water-tight either by means of cup-leathers of the usual form, as shown at *a a*, in Fig. 4166; many other arrangements may be employed to render the piston water-tight.

4166.



This weighing machine, like many hydraulic contrivances, is only a particular application of the principle upon which Timothy Bramah constructed his famous press, of which we treat next.

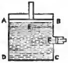
The Hydrostatic or Bramah Press.—The following article on Bramah's Press is taken from Alexander Jamieson's excellent work, Mechanics of Fluids for Practical Men;—

If there be any number of pistons of different magnitudes, anyhow applied to apertures in a cylindrical vessel filled with an incompressible and non-elastic fluid,

The forces acting on the piston to maintain an equilibrium, will be to one another as the areas of the respective apertures, or the squares of the diameters of the pistons.

Let A B C D, Fig. 4167, represent a section passing along the axis of a cylindrical vessel filled with an incompressible and non-elastic fluid, and let E F be two pistons of different magnitudes, connected with the cylinder and closely fitted to their respective apertures or orifices; the piston F being applied to the aperture in the side of the vessel, and the piston E occupying an entire section of the cylinder or vessel, by which the fluid is contained. Then, because by the nature of fluidity the pressures on every part of the pistons E and F are mutually transmitted to each other through the medium of the intervening fluid, it follows that these pressures will be in a state of equilibrium when they are equal among themselves.

4167.



Now it is manifest that the sum of the pressures propagated by the piston E is proportional to the area of a transverse section of the cylinder; and in like manner the sum of the pressures propagated by the piston F is proportional to the area of the aperture which it occupies; consequently an equilibrium must obtain between these pressures,

When the forces on the pistons are to one another respectively as the areas of the apertures or spaces which they occupy.

And it is obvious that the same thing will take place, whatever may be the number of the pistons pressed.

Hence it appears that by taking the areas of the pistons E and F in a proper ratio to one another, we can, by means of an incompressible fluid, produce an enormous compression, and that too by the application of a very small force.

Put $P =$ the force or pressure on the piston E,
$A =$ the area of the orifice which it occupies,
$p =$ the pressure on the piston F, and
$a =$ the area of the orifice or space to which it is fitted.

Then, according to the principle announced in the foregoing proposition and demonstrated above, we shall obtain $a : A :: p : P$.

But because, by the principles of mensuration, the areas of different circles are to one another as the squares of their diameters; if therefore we substitute d^2 and D^2 respectively for a and A in the above analogy, we shall have $d^2 : D^2 :: p : P$, and from this, by making the product of the mean terms equal to the product of the extremes, we get

$$p\,D^2 = P\,d^2. \qquad [A]$$

This is the principle upon which depends the construction and use of that very powerful instrument, the *Hydrostatic Press*, first brought into notice about the year 1796, by Joseph Bramah, of London, who announced it to the world as the discovery of a new mechanical power. In this, however, he was mistaken, for although the principle upon which it depends may be said to constitute a seventh mechanical power, yet the principle was not new to philosophers at the time when Bramah applied it to the construction of his presses, it having long been familiarly known under the designation of the *Hydrostatic Paradox*; and besides, the celebrated Pascal obscurely hinted at its application to mechanical purposes, but did not pursue the idea far enough to produce anything useful, or to entitle him to the merit of the discovery.

The improvement introduced by Bramah consisted in the application of the common forcing pump to the injection of water, or some other incompressible and non-elastic fluid, into a strong metallic cylinder, truly bored and furnished with a movable piston, made perfectly water-tight by means of leather collars or packing, neatly fitted into the cylinder.

The proportion which subsists between the diameter of this piston and that of the plunger in the forcing pump, constitutes the principal element by which the power of the instrument is calculated; for, by reason of the equal distribution of pressure in the fluid, it is evident that whatever force is applied, that force must operate alike on the piston in the cylinder, and on the plunger in the forcing pump, and consequently,

In proportion as the area of the transverse section of the one exceeds the area of a similar section of the other, so must the pressure sustained by the one exceed that sustained by the other.

Therefore if the piston F in the preceding diagram be assimilated to the plunger in the barrel of a forcing pump, and the piston E to that in the cylinder of the hydrostatic press; then the equation marked [A], notwithstanding the very simple and concise form in which it appears, involves every particular respecting the power and effects of the engine.

This being premised, we shall now proceed to exhibit the use and application of the formula, by the resolution of the following practical examples.

Ex. 1.—If the diameter of the cylinder is 5 in., and that of the forcing pump 1 in.; what is the pressure on the piston in the cylinder, supposing the force applied on the plunger or smaller piston to be equivalent to 750 lbs.?

Here we have given $D = 5$ in.; $d = 1$ in., and $p = 750$ lbs.; therefore, by substitution, equation [A] becomes $5^2 \times 750 = P \times 1^2$; that is, $P = 18750$ lbs.

Or the equation for the value of P may be expressed in general terms as follows; $P = \frac{p D^2}{d^2}$.

And from the equation in its present form we deduce the following practical rule.

Rule.—*Multiply the square of the diameter of the cylinder by the magnitude of the power applied, and divide the product by the square of the diameter of the forcing pump, and the quotient will express the intensity of the pressure on the piston of the cylinder.*

Ex. 2.—If the diameter of the cylinder is 5 in., and that of the forcing pump 1 in.; what is the magnitude of the power applied, supposing the entire pressure on the piston of the cylinder to be 18750 lbs.?

Here we have given $D = 5$ in.; $d = 1$ in., and $P = 18750$ lbs.; therefore, by substitution, equation [A] becomes $5^2 \times p = 18750 \times 1^2$; or $p = 750$ lbs.

If both sides of the fundamental equation [A] be divided by D^2, the general expression for the value of p is $p = \frac{P d^2}{D^2}$.

And the practical rule which this equation supplies may be expressed in words at length in the following manner.

Rule.—*Multiply the given pressure on the piston of the cylinder by the square of the diameter of the forcing pump, and divide the product by the square of the diameter of the cylinder for the power required.*

Ex. 3.—The diameter of the forcing pump is 1 in., and the power with which the plunger descends is equivalent to 750 lbs.; what must be the diameter of the cylinder, to admit a pressure of 18750 lbs. on the piston?

Here we have given $d = 1$ in.; $p = 750$ lbs., and $P = 18750$ lbs.; consequently, by substitution, the equation marked [A] becomes $750\ D^2 = 18750 \times 1^2$; hence, by division, we obtain $D^2 = \frac{18750}{750} = 25$; consequently, by evolution, we have $D = \sqrt{25} = 5$ in.

If both sides of the equation [A] be divided by p, and the square root of the quotient extracted, the general expression for the diameter of the piston is $D = \sqrt{\frac{P d^2}{p}}$.

And the practical rule for the determination of D may be expressed in words as follows.

Rule.—*Multiply the pressure on the piston of the cylinder by the square of the diameter of the forcing pump, and divide the product by the force with which the plunger descends; then the square root of the quotient will be the diameter of the cylinder sought.*

Ex. 4.—The diameter of the cylinder is 5 in., and the force with which the plunger descends is equivalent to 750 lbs.; what must be the diameter of the forcing pump, in order to transmit a pressure of 18750 lbs. to the piston of the cylinder?

Here we have given $D = 5$ in.; $p = 750$ lbs., and $P = 18750$ lbs.; consequently, by substitution, equation [A] becomes $18750\, d^2 = 750 \times 5^2$, and by division we shall have $d^2 = \frac{750 \times 25}{18750} = 1$; therefore, by extracting the square root, we get $d = \sqrt{1} = 1$ in.

If both sides of the original equation marked [A] be divided by P, and the square root extracted, the entire pressure on the piston, the general expression for the value of d becomes $d = \sqrt{\frac{p D^2}{P}}$.

And the practical rule which this equation supplies may be expressed in the following manner.

Rule.—*Multiply the force with which the plunger descends by the square of the diameter of the cylinder, and divide the product by the entire pressure on the piston; then extract the square root of the quotient for the diameter of the forcing pump.*

The foregoing is the theory of the hydrostatic press, as restricted to the consideration of the diameters of the cylinder and forcing pump, and the respective pressures on the piston and plunger; but since the instrument is generally furnished with an *indicator* or *safety-valve* for measuring the intensity of pressure, the theory would be incomplete without considering it in connection with the diameters of the pump and cylinder. For which purpose

Put δ = the diameter of the safety-valve, expressed in inches or parts,
and w = the weight thereon, or the force that prevents its rising.

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Then, according to the principle announced, p. 1983, we obtain the following analogies, namely;—

$$D^2 : \delta^2 :: P : w,$$
$$d^2 : \delta^2 :: p : w;$$

and from these analogies, by making the products of the extreme terms equal to the products of the means, we get

$$D^2 w = \delta^2 P, \qquad [B]$$
$$\text{and} \quad d^2 w = \delta^2 p. \qquad [C]$$

Now, in order to pursue the expansion of these equations, we shall suppose the value of δ to be one-fourth of an inch, while the numerical values of the other letters remain the same as supposed for the several examples under equation [A]; then, to determine the corresponding value of w, or the power which prevents the safety-valve from rising, when all the parts of the instrument, or the several powers and pressures, are in a state of equilibrium, we have the following examples to resolve according to the proposed conditions.

Ex. 5.—The diameter of the cylinder is 5 in., that of the indicator or safety-valve ¼ of an inch, and the entire pressure upon the piston of the cylinder 18750 lbs.; what is the corresponding force preventing the ascent of the safety-valve, on the supposition of a perfect equilibrium?

Here we have given $D = 5$ in.; $\delta = \frac{1}{4}$ of an inch, and $P = 18750$ lbs.: consequently, by substitution, the equation [B] becomes $5^2 w = \cdot 25^2 \times 18750$; from which, by division, we get

$$w = \frac{\cdot 0625 \times 18750}{25} = 46 \cdot 875 \text{ lbs.}$$

But the general expression for the value of w, as derived from the equation [B], becomes $w = \frac{\delta^2 P}{D^2}$, from which we derive the following rule.

Rule.—*Multiply the entire pressure on the piston of the cylinder by the square of the diameter of the indicator or safety-valve, and divide the product by the square of the diameter of the cylinder for the weight required.*

Ex. 6.—The diameter of the safety-valve is ¼ of an inch, that of the cylinder 5 in., and the weight on the safety-valve 46·875 lbs., what is the corresponding pressure on the piston of the cylinder?

Here we have given $\delta = \frac{1}{4}$ of an inch; $D = 5$ in., and $w = 46 \cdot 875$ lbs.; therefore, by substitution, equation [B] becomes $\cdot 25^2 P = 5^2 \times 46 \cdot 875$, and by division we obtain

$$P = \frac{1171 \cdot 875}{\cdot 0625} = 18750 \text{ lbs.}$$

The general expression for the value of P, as derived from the equation marked [B], becomes

$$P = \frac{D^2 w}{\delta^2}.$$

And the practical rule supplied by this equation may be expressed in words as follows.

Rule.—*Multiply the weight on the safety-valve by the square of the diameter of the cylinder, and divide the product by the square of the diameter of the safety-valve, and the quotient will give the entire pressure on the piston of the cylinder.*

Ex. 7.—The diameter of the cylinder is 5 in., the entire pressure of the piston is 18750 lbs., and the weight on the safety-valve is 46·875 lbs.; what is its diameter?

Here we have given $D = 5$ in.; $P = 18750$ lbs., and $w = 46 \cdot 875$ lbs.; therefore, by substitution, equation [B] becomes $18750\, \delta^2 = 5^2 \times 46 \cdot 875$, and from this, by division, we get $\delta^2 = \frac{5^2 \times 46 \cdot 875}{18750} = \cdot 0625$; and by extracting the square root, we obtain $\delta = \sqrt{\cdot 0625} = \cdot 25$, or ¼ of an inch.

The general expression for the value of δ, as derived from the equation [B], is as follows, namely, $\delta = \sqrt{\frac{D^2 w}{P}}$.

And the practical rule which this equation affords may be expressed in words in the following manner.

Rule.—*Multiply the load on the safety-valve by the square of the diameter of the cylinder, divide the product by the entire pressure on the piston, and the square root of the quotient will give the diameter of the safety-valve required.*

Ex. 8.—The diameter of the safety-valve is ¼ of an inch, the load upon it 46·875 lbs., and the entire pressure on the piston of the cylinder is 18750 lbs.; what is its diameter?

Here we have given $\delta = \frac{1}{4}$ of an inch, $w = 46 \cdot 875$ lbs., and $P = 18750$ lbs.: consequently, by substitution, we have $46 \cdot 875\, D^2 = \cdot 25^2 \times 18750$, from which, by division, we shall obtain $D^2 = \frac{\cdot 25^2 \times 18750}{46 \cdot 875} = 25$, and finally, by extracting the square root, we get $D = \sqrt{25} = 5$ in.

If both sides of the equation marked [B] be divided by w, the weight on the safety-valve, we get $D^2 = \frac{\delta^2 P}{w}$, and by extracting the square root, the general expression for the value of D, the diameter of the cylinder, becomes $D = \sqrt{\frac{\delta^2 P}{w}}$. And from this equation we derive the following rule.

Rule.—*Multiply the entire pressure on the piston of the cylinder by the square of the diameter of the safety-valve, divide the product by the weight upon the safety-valve, and extract the square root of the quotient for the diameter of the cylinder sought.*

Ex. 9.—The diameter of the forcing pump is 1 in., that of the safety-valve is ¼ of an inch, and the power or force with which the plunger descends is equivalent to 750 lbs.; what is the corresponding weight on the safety-valve?

Here we have given $d = 1$ in.; $\delta = \frac{1}{4}$ of an inch, and $p = 750$ lbs.; consequently, by substitution, the equation [C] becomes $1^2 \times w = \cdot 25^2 \times 750$; that is, $w = 46 \cdot 875$ lbs., the very same value as we derived from the fifth example.

If both sides of the equation marked [C] be divided by d^2, the general expression for the value of w becomes $w = \frac{\delta^2 p}{d^2}$.

And the practical rule supplied by this equation may be expressed in words at length in the following manner.

Rule.—*Multiply the force with which the plunger descends by the square of the diameter of the safety-valve, and divide the product by the square of the diameter of the plunger; then the quotient will express the load upon the safety-valve.*

Ex. 10.—The diameter of the safety-valve is ¼ of an inch, that of the forcing pump is 1 in., and the load upon the safety-valve is 46·875 lbs.; what is the power applied, or the force with which the plunger in the forcing pump descends?

Here we have given $\delta = \frac{1}{4}$ of an inch, $d = 1$ in., and $w = 46 \cdot 875$ lbs.; consequently, by substitution, equation [C] becomes $\cdot 25^2 p = 46 \cdot 875 \times 1^2$, and from this, by division, we obtain

$$p = \frac{46 \cdot 875}{\cdot 0625} = 750 \text{ lbs.}$$

The general expression for the value of p, as obtained from the equation marked [C], becomes $p = \frac{d^2 w}{\delta^2}$, from which we derive the following rule.

Rule.—*Multiply the load on the safety-valve by the square of the diameter of the forcing pump, then divide the product by the square of the diameter of the safety-valve, and the quotient will give the force with which the piston descends.*

Ex. 11.—The diameter of the plunger or the piston of the forcing pump is 1 in., the force with which it descends is equivalent to 750 lbs., and the load on the safety-valve is 46·875 lbs.; what is its diameter?

Here we have given $d = 1$ in., $p = 750$ lbs., and $w = 46 \cdot 875$ lbs.; consequently, by substitution, we have $750\,\delta^2 = 1^2 \times 46 \cdot 875$, and from this, by division, we obtain $\delta^2 = \frac{46 \cdot 875}{750} = \cdot 0625$, and finally, by evolution, we have $= \delta \sqrt{\cdot 0625} = \cdot 25$ of an inch.

Let both sides of the equation marked [C] be divided by p, the power or force with which the piston of the forcing pump descends, and we shall have $\delta^2 = \frac{d^2 w}{p}$, and by extracting the square root we get $\delta = \sqrt{\frac{d^2 w}{p}}$. Hence the following practical rule.

Rule.—*Multiply the weight or load upon the safety-valve by the square of the diameter of the forcing pump, and divide the product by the force with which the plunger or piston of the forcing pump descends; then the square root of the quotient will be the diameter of the safety-valve.*

Ex. 12.—The diameter of the safety-valve is ¼ of an inch, the weight upon it is 46·875 lbs., and the power applied, or the force with which the plunger descends, is 750 lbs.; what is the diameter of the forcing pump?

Here we have given $\delta = \frac{1}{4}$ of an inch, $w = 46 \cdot 875$ lbs., and $p = 750$ lbs.; consequently, by substitution, the equation marked [C] becomes $46 \cdot 875\, d^2 = \cdot 25 \times 750$; therefore, by division, we obtain $d^2 = \frac{\cdot 25^2 \times 750}{46 \cdot 875} = 1$, and finally, by extracting the square root, we get $d = 1$ in.

The general expression for the value of the diameter of the forcing pump, as derived from the equation [C], is $d = \sqrt{\frac{\delta^2 p}{w}}$. And from this we obtain the following practical rule.

Rule.—*Multiply the force with which the piston of the forcing pump descends by the square of the diameter of the safety-valve, divide the product by the load on the safety-valve, and extract the square root of the quotient for the diameter of the forcing pump.*

The foregoing twelve examples exhibit all the varieties of cases that can arise from the combination of the six data which we have employed in our theory, namely, the diameters of the cylinder, the forcing pump, and the safety-valve; together with the entire pressure on the piston of the cylinder, the power applied to the plunger of the forcing pump, and the weight upon the safety-valve.

We have determined each of the quantities composing the several fundamental equations in terms of the others, and have drawn up rules from the general expressions, merely for the assistance of those who are not accustomed to algebraic reductions; those who are will prefer finding each quantity directly from the general equation expressing its value.

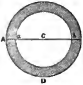
It is manifest from the principles of mensuration that the area of a transverse section of the cylinder, or the base of the piston, is expressed by $\cdot 7854\, D^2$; and we have shown that the entire pressure upon the base of the piston in the case of equilibrium is $P = \frac{p D^2}{d^2}$, and $P = \frac{D^2 w}{\delta^2}$; consequently, if n denotes the pressure in pounds avoirdupois on one square inch of the piston, then we have

$$n = \frac{P}{\cdot 7854\, D^2};\ p = \frac{p}{\cdot 7854\, d^2},\ \text{and}\ n = \frac{w}{\cdot 7854\, \delta^2}. \qquad [D]$$

Now, from principles investigated by Peter Barlow, it appears that if c denote the cohesive force of the material employed in the construction of the cylinder, t its thickness, and r the interior radius, then, in order that the strain produced by the pressure shall not exceed the elastic power of the material, it is necessary that $n = \frac{c\,t}{t + r}$.

In order to demonstrate this, let A B D, Fig. 4168, be a transverse section of the cylinder, perpendicular to the axis passing through C; then, supposing a certain uniform pressure to be exerted all round the interior boundary, it will readily appear, from the theory of resistance, that each successive circular lamina, estimated from the interior towards the exterior circumference, offers a less and less resistance to the straining force.

4168.



But it is obvious from the very nature of the subject that by reason of the internal pressure or strain the metal must undergo a certain degree of extension; and since the resistance of the outer boundary is less than that of the inner one, it follows that the extension must also be less. This is manifest, for the resistance which any body offers to the force by which it is strained is proportional to the extension which it undergoes divided by its length. Now, since the resistances of the several laminæ decrease as they recede from the interior boundary towards the exterior, while at the same time the corresponding circumferences increase, it is manifest that the extension for the several laminæ decreases to the last or exterior boundary, where it is the least of all. It is therefore the law of the decreasing resistance that the present inquiry is instituted to determine.

Put $d = a\,b$, the interior diameter of the cylinder before the pressure is applied,
e = the increase of d occasioned by the pressure,
d' = A B, the exterior diameter in its original state,
e' = the increase induced by pressure.

Then $(d + e)$ and $(d' + e')$ are respectively the interior and exterior diameters of the cylinder as affected by extension.

By the principles of mensuration, the area of the annulus, or circular ring contained between the interior and exterior boundaries,

Is equal to the difference of the squares of the diameters, drawn into the constant fraction 0·7854; *or it is proportional to the sum of the diameters, drawn into their difference.*

But according to the nature of the present inquiry, the area of the ring is the same, both before and after the extension takes place; consequently we have $(d' + e')^2 - (d + e)^2 = d'^2 - d^2$; therefore, by expanding the terms on the left-hand side, we get $d'^2 + 2\,d'\,e' + e'^2 - d^2 - 2\,d\,e - e^2 = d'^2 - d^2$; or, by transposing and expunging the common terms, it is $2\,d'\,e' + e'^2 = 2\,d\,e + e^2$; and this equation being converted into an analogy, gives $2\,d' + e' : 2\,d + e :: e : e'$.

Now, the quantity of extension that the material will allow before rupture being very small, especially as compared with the quantities $2\,d'$ and $2\,d$, it therefore follows that the quantities e' and e, in the first and second terms, may be conceived to vanish, and the above analogy becomes $d' : d :: e : e'$.

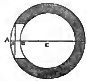
From this it appears that the extensions of the respective circumferences are inversely as the corresponding diameters; but we have stated above that the resistance is as the extension divided by the length; therefore we have $\frac{d}{d'} : \frac{d'}{d}$, or, which amounts to the same thing, $d^2 : d'^2$; hence this law, that the magnitude of the resistance offered by each successive circular lamina,

Is inversely as the square of its diameter, or, which is the same thing, inversely as the square of its distance from the common centre to which they are referred.

From the general law thus established, the actual resistance due to any point in the annulus, or to any thickness of metal, can very easily be ascertained.

Put r = C a, the interior radius of the cylinder, of which the annexed diagram, Fig. 4169, is a section,
t = a A, the entire thickness of the metal,
x = $a\,n$, any variable thickness estimated from a, the interior surface,
n = the pressure on a square inch of the inner surface in pounds avoirdupois,
f = the measure of the straining force, or the resistance sustained by the first or interior lamina; and
c = the cohesive force of the material.

4169.



Then, agreeably to the law of the resistances which we have established above, we have $(r + x)^2 : r^2 :: f : \frac{f\,r^2}{(r + x)^2}$; this result expresses the strain at the point x, or the resistance of the material whose thickness is a n; and the fluxion of this quantity, as referred to the variable thickness x, is flux. $= \frac{f r^2 \dot{x}}{(r+x)^2}$; consequently the fluent, or the sum of all the strains, is $\int \frac{f r^2 \dot{x}}{(r+x)^2} + C$, and this when $x = t$ becomes

$$f\left(r - \frac{r^2}{r+t}\right) = \frac{f r t}{r+t}.$$

Therefore if the strain or resistance f were to act uniformly on the thickness expressed by $\frac{f r t}{r+t}$, it would produce the same effect as if all the variable strains were to act on the whole thickness t.

The above law being admitted, let us suppose that the interior radius of the cylinder, and the pressure a square inch on the surface are given, and let it be required to determine the thickness such that the strain and resistance may be in equilibrio.

Here it is manifest that the greatest strain the thickness $\frac{r t}{r+t}$ can resist is $\frac{c r t}{r+t}$, and the strain to which it is actually exposed is $n r$; consequently, when these are equal, we have $n r = \frac{c r t}{r+t}$; from which, by expunging the common factor r, we get

$$n = \frac{c t}{r+t}. \qquad [E]$$

If this value of n be compared with its respective values as indicated in the equations [D] preceding, we shall have the following expressions for the thickness of metal in the cylinder to resist any pressure, while the elastic power of the material remains perfect, namely ;—

$$t = \frac{P r}{\cdot 7854\, c\, D^2 - P};\ t = \frac{p r}{\cdot 7854\, c\, d^2 - p},\ \text{and}\ t = \frac{w r}{\cdot 7854\, c\, \delta^2 - w}.$$

Therefore, if for c in each of the preceding expressions we substitute its value as determined by experiment, and which for cast iron, according to Dr. Robison, is 16648 lbs. avoirdupois upon a square inch, then we shall have

$$t = \frac{P r}{13076\, D^2 - P}, \qquad [F]$$

$$t = \frac{p r}{13076\, d^2 - p}, \qquad [G]$$

$$t = \frac{w r}{13076\, \delta^2 - w}. \qquad [H]$$

Where the constant number $13076 = 16648 \times \cdot 7854$.

The following example will illustrate the use of these equations, the value of t the thickness of the metal coming out the same by each.

Ex. 13.—What must be the thickness of metal in the cylinder of a hydrostatic press to resist a pressure of 30000 lbs., the diameter of the cylinder being 5 in., that of the forcing pump 1 in., and of the safety-valve ¼ of an inch, being the same dimensions which we have employed in the preceding examples?

Here we have given $P = 30000$ lbs.; $D = 5$ in.; and consequently, $r = 2\frac{1}{2}$ in.; therefore, by substitution, equation [F] gives $t = \frac{30000 \times 2\frac{1}{2}}{13076 \times 5^2 - 30000} = \cdot 253$ in., being something more than ¼ of an inch.

In order that the entire pressure on the piston of the cylinder may be equal to 30000 lbs. according to the conditions of the question, the force with which the plunger of the forcing pump descends must be equal to 1200 lbs.; therefore by equation [G] we have

$$t = \frac{1200 \times 2\frac{1}{2}}{13076 \times 1^2 - 1200} = \cdot 253 \text{ in., the same as before.}$$

Again, in order that the entire pressure may be equal to 30000 lbs., the weight upon the safety-valve must be 75 lbs.; hence from equation [H] we obtain $t = \frac{75 \times 2\frac{1}{2}}{13076 \times \cdot 25^2 - 75} = \cdot 253$ in., the same as in the two cases foregoing.

It may not be improper here to remark, that although the requisite thickness of metal is alike assignable from either of the above equations, when the respective pressure and diameters are known, yet it is the first of the class only, or that marked [F], which becomes available in practice, and for this reason, that the power of the press, or the aggregate pressure which it is capable of exciting, is known *a priori*, or immediately assignable from the conditions of construction, while the load upon the safety-valve, and the force with which the plunger descends, have each to be determined by calculations founded on circumstances connected with the aggregate or ultimate pressure.

Referring to equation [E], which has been purposely investigated for expressing the intensity of pressure on a square inch of surface, and multiplying both sides by $r + t$, the denominator of the fraction, we shall have $a\,r + a\,t = c\,t$, from which, by transposing and collecting the terms, we get $(c - a)\,t = a\,r$; then by division, the value of t, or the thickness of metal in the cylinder to withstand the pressure, becomes

$$t = \frac{a\,r}{c - a}. \qquad [\mathrm{K}]$$

From which it appears, that if a constant value adapted to practical purposes can be assigned to a, the rule for calculating the thickness of metal in the cylinder will become exceedingly simple.

Now, it has been remarked by several eminent practical engineers, as well as by the most approved and intelligent manufacturers, that the extreme pressure on a square inch of the piston should never exceed half the cohesive power of the material; but, according to Dr. Robison, the cohesive power of cast iron of a medium quality is equal to 16648 lbs.; hence we have

$$a = \frac{16648}{2} = 8324 \text{ lbs.};$$

therefore, if 8324 lbs. be adopted as the limit of pressure upon a square inch of surface, the foregoing value of t becomes $t = \frac{8324\,r}{16648 - 8324} = r$. There is no occasion to limit the pressure to the piston only, since every square inch of surface in contact with the fluid sustains the same pressure. This limitation has frequently caused a misapprehension respecting the mode of ascertaining the pressure on an inch of surface.

Consequently, in order that the strain produced by the pressure may not exceed the elastic power of the material,

The thickness of metal ought never to be less than the interior radius of the cylinder.

By the first equation of class [D] it has been shown that the pressure on a square inch of the piston in lbs. avoirdupois is $a = \frac{P}{\cdot 7854\,D^2}$, or by substituting the foregoing value of a, it is $8324 = \frac{P}{\cdot 7854\,D^2}$; from which, by multiplication, we obtain $8324 \times \cdot 7854\,D^2 = P$; but in order to express the pressure in tons, it is

$$P = \frac{6537 \cdot 6696\,D^2}{2240} = 2 \cdot 9186\,D^2. \qquad [\mathrm{L}]$$

Therefore, when the diameter of the cylinder is given, the entire pressure in tons is determined by the following very simple rule.

Rule.—*Multiply the square of the diameter in inches by the constant number* 2·9186, *and the product will be the pressure in tons.*

And again, when the pressure in tons is given, the diameter of the cylinder may be determined by reversing the process, or by the following rule.

Rule.—*Divide the given pressure in tons by the constant number* 2·9186, *and extract the square root of the quotient, for the diameter of the cylinder in inches.*

The preceding theory, as we have developed it, unfolds every particular connected with the hydrostatic press, and by paying proper attention to the equations, rules, and examples, as we have delivered them, every difficulty attending the construction of the instrument will be removed; to practical persons, however, that part of the theory exhibited in the equations marked [K] and [L] will be found the most valuable, as they do the more immediately contain the particulars which direct their operations. The following examples will prove the truth of these remarks.

Ex. 14.—The diameter of the cylinder in a hydrostatic press is 10 in.; what is its power, or what pressure does it transmit?

Here by the first rule above, we have $P = 10^2 \times 2 \cdot 9186 = 291 \cdot 86$ tons.

Ex. 15.—What is the diameter, and what the thickness of metal, in a press of 300 tons power?

By the second rule above, we have $D^2 = 300 \div 2 \cdot 9186 = 102 \cdot 81$ nearly; therefore, by extracting the square root, we obtain $D = \sqrt{102 \cdot 81} = 10 \cdot 13$ in.; consequently, according to the remark under the equation [K], the thickness of metal is $t = 10 \cdot 13 \div 2 = 5 \cdot 065$ in.

The rules by which the preceding examples have been resolved were very nearly, but not precisely, the same as those employed by Joseph and Timothy Bramah in the construction of their excellent presses; the only difference, however, consists in their assuming a higher number as the limit of pressure, the standard which they employed being 8556 lbs. upon a square inch of the piston, thereby indicating that they reckoned on a higher cohesive power in the material than that which we have adopted as the basis of our theory.

Now, 8556 lbs. on a square inch is equivalent to 6619·8824 lbs. upon a circular inch; whereas the constant which we have chosen is only 6537·6696 lbs., being a difference of 82·2128 lbs. upon the circular inch, a difference that need not be regarded in practice, as the error will always fall on the side of safety, giving a smaller power to the press than it really possesses.

It sometimes, indeed it very frequently, happens that presses are constructed without any attention being paid to the relation which subsists between the strength of the parts and the strain which they have to resist; in all such cases, therefore, it may be interesting to possess a rule by which the merits or demerits of a press so constructed can be ascertained, for in this way a failure in the instrument may be prevented, and a remedy applied to any defect that may exist.

Now, according to the first equation of class [D], the pressure upon a square inch is $s = \frac{P}{\cdot 7854\,D^2}$, and according to equation [E], it is $s = \frac{c\,t}{r + t}$; therefore, by comparison, we have $\frac{P}{\cdot 7854\,D^2} = \frac{c\,t}{r + t}$; consequently, by multiplying and substituting the cohesive power of cast iron, we have $(t + r)\,P = 13076\,D^2\,t$.

Let $4\,r^2$ be substituted in this equation instead of D^2, its equivalent, and we shall obtain $(t + r)\,P = 52304\,r^2\,t$; consequently the pressure in tons is $P = \frac{52304\,r^2\,t}{2240\,(t + r)} = \frac{23 \cdot 35\,r^2\,t}{(t + r)}$.

From which it appears, that by knowing the interior radius of the cylinder and the thickness of the metal, the power of the press can easily be ascertained; the following is the rule for that purpose.

Rule.—*Multiply* 23·35 *times the thickness of metal by the square of the radius of the cylinder, and divide the product by the radius plus the thickness of metal, and the quotient will give the power of the press in tons.*

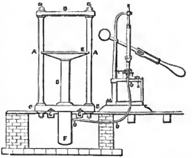
Ex. 16.—A hydrostatic press is so constructed as to have the interior radius of its cylinder equal to 3 in., and the thickness of metal 4 in.; now this press is designed for packing flax, and is estimated to stand a pressure of 180 tons; query if its power is not overrated?

According to the above rule, it is $P = \frac{23 \cdot 35 \times 3^2 \times 4}{4 + 3} = 120 \cdot 08$ tons; consequently the power of the press is overrated by about 60 tons, being one-third less than the estimated pressure according to the question.

The thickness of metal necessary to resist a pressure of 180 tons, or 403200 lbs., is equal to 17·9 in. nearly, and the proposed thickness is only 4 in., being less than one-fourth of the thickness which is really necessary to resist the strain; hence we infer that the press in its present state is entirely unfitted for its intended purpose, and altogether inconsistent with safety and precision of operation.

The hydrostatic press, in its present state of improvement, is a machine that is capable of generating and transmitting a greater degree of force, for the purpose of overcoming immense resistances, and raising enormous loads to a small height, than any other instrument or engine with which we are acquainted; it is therefore of the highest importance that the principles of its construction and the mode of operation should be rightly understood, and in order to render the subject as clear and intelligible as possible, we think proper to lay before our readers the following detailed description.

4170.



The woodcut, Fig. 4170, exhibits an elevation of the press in its complete state, accompanied by the forcing pump and all its appurtenances as fitted up for immediate action. F is a strong metallic cylinder of cast iron, or some other material of sufficient density to prevent the fluid from issuing through its pores, and of sufficient strength to preclude the possibility of rupture, by reason of the immense pressure which it is destined to withstand.

The cylinder F is bored and polished with the most scrupulous precision, and fitted with the movable piston D, which is rendered perfectly water-tight, by means of leather collars constructed for the purpose, and fixed in the cylinder by a simple but ingenious contrivance to be described hereafter.

Into this side or base of the cylinder F, the end of a small tube *b b b* is inserted, and by this tube the water is conveyed or forced into the cylinder; the other end of the tube is attached to the forcing pump, as represented in the diagram.

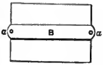
A A are two very strong upright bars, generally made of wrought iron, and of any form whatever, corresponding to the notches in the sides of the flat table E, which is fixed upon the end of the piston D, and by workmen is usually denominated the follower or pressing table.

B is the top of the frame into which the upright bars A A are fixed, and *c c* is the bottom thereof, both of which are made of cast, in preference to wrought, iron, being both cheaper and more easily moulded into the intended form.

The bottom of the frame *c c* is furnished with four projections or lobes, with circular perforations, for the purpose of fastening it by iron bolts to the massive blocks of wood, whose transverse sections are shown at G G. The top B has two similar perforations, through which are passed the upper extremities of the vertical bars A A, and there made fast, by screwing down the cup-nuts represented at *a* and *a*.

Fig. 4171 represents the plan of the top, or as it is more frequently termed, the head of the frame; the lower side or surface of which is made perfectly smooth, in order to correspond with, and apply to the upper surface of the pressing table E in Fig. 4170; this correspondence of surfaces becomes necessary on certain occasions, such as the copying of prints, taking fac-similes of letters, and the like; in all such cases it is manifest that smooth and coincident surfaces are indispensable for the purpose of obtaining true impressions.

4171.



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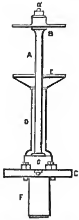

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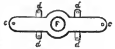

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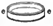

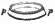

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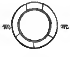


Fig. 4171 represents the upper side of the block, where it is evident that the middle part B (through whose rounded extremities *a* and *a* the circular perforations are made for receiving the upright bars or rods A A, Fig. 4170) is considerably thicker than the parts on each side of it; this augmentation of thickness is necessary to resist the immense strain that comes upon it in that part; for although the pressure may be equally distributed throughout the entire surface, yet it is obvious that the mechanical resistance to fracture must principally arise from that part, which is subjected to the reaction of the upright bars.

Fig. 4172 represents the plan of the base or bottom of the frame; it is generally made of uniform thickness, and of sufficient strength to withstand the pressure, for be it understood that all the parts of the machine are subjected, to the same quantity of strain, although it is exerted in different ways. The upright bars, cylinders, and connecting tubes, resist by tension, the pistons by compression, and the pressing table, together with the top and bottom of the frame, resist transversely.

The circular perforations *c c* correspond to *a a* in the top of the frame, and receive the upright bars in the same manner; the perforations *d d d d* receive the screw-bolts which fix the frame to the beams of timber represented at G G, Fig. 4170; the large perforation F receives the cylinder, the upper extremity of which is furnished with a flange, for the purpose of fitting the circular swell around the perforation, and preventing it from moving backwards during the operation of the instrument.

A side view of the engine is represented in Fig. 4173, where the same letters of the alphabet refer to the same parts of the structure.

F is the cylinder into which the fluid is injected; D, the piston, on whose summit is the pressing table E; A, one of the upright rods or bars of malleable iron; B, the head of the press, fixed to the upright bar A by means of the cup-nut *a*; *c*, the bottom, in which the upright bar is similarly fixed; and G a beam of timber supporting the frame with all its appendages.

But the hydrostatic press, as here described and constructed, must not be considered as fit for immediate action; for it is manifestly impossible to bore the interior of the cylinder so truly, and to turn the piston with so much precision, as to prevent the escape of water between their surfaces, without increasing the friction to such a degree that it would require a very great force to counterbalance it.

In order therefore to render the piston water-tight, and to prevent as much as possible the increase of friction, recourse must be had to other principles, which we now proceed to explain.

The piston D is surrounded by a collar of pump-leather *o o*, represented in Fig. 4174, which collar being doubled up, so as in some measure to resemble a lesser cup placed within a greater, it is fitted into a cell made for its reception in the interior of the cylinder; and when there, the two parts are prevented from coming together by means of the copper ring *p p*, represented in Fig. 4175, being inserted between the folds, and retained in its place by a lodgment made for that purpose on the interior of the cylinder.

The leather collar, first arranged in its present form by Benjamin Hick, is kept down by means of a brass or bell-metal ring *m m*, Fig. 4176, which ring is received into a recess formed round the interior of the cylinder, and the circular aperture is fitted to admit the piston D to pass through it, without materially increasing the effects of friction, which ought to be avoided as much as possible.

The leather is thus confined in a cell, with the edge of the inner fold applied to the piston D, while the edge of the outer fold is in contact with the cylinder all around its interior circumference; in this situation the pressure of the water acting between the folds of the leather, forces the edges into close contact with both the cylinder and piston, and renders the whole water-tight; for if the leather be properly constructed and rightly fitted into its place, it is almost impossible that any of the fluid can escape; for the greater the pressure the closer will the leather be applied to both the piston and the cylinder.

The metal ring *m m* is truly turned in a lathe, and the cavity in which it is placed is formed with the same geometrical accuracy; but in order to fix it in its cell it is cut into five pieces by a very fine saw, as represented by the lines in the diagram, which are drawn across the surface of the ring. The four segments which radiate to the centre are put in first, then the segment formed by the parallel kerfs (the copper ring *p p* and the leather collar *o o* being previously introduced), and lastly, the piston which carries the pressing table.

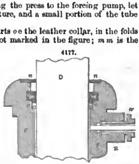
That part of the cylinder above the ring *m m* where the inner surface is not in contact with the piston is filled with tow or some other soft material of a similar nature; the material thus inserted has a twofold use; in the first place, when saturated with sweet oil, it diminishes the friction that necessarily arises when the piston is forced through the ring *m m*; and in the second place, it prevents the admission of any extraneous substance which might increase the friction or injure the surface of the piston, and otherwise lessen the effects of the machine.

The packing here alluded to is confined by a thin metallic annulus, neatly fitted and fixed on the top of the cylinder, the circular orifice being of sufficient diameter to admit of a free and easy motion to the piston.

If a cylinder thus furnished with its several appendages be placed in the frame, and the whole firmly screwed together, and connected with the forcing pump, as represented in Fig. 4170, the press is completed and ready for immediate use; but in order to render the construction still more explicit and intelligible, and to show the method of connecting the press to the forcing pump, let Fig. 4177 represent a section of the cylinder with all its furniture, and a small portion of the tube immediately adjoining, by which the connection is effected.

Then is F F the cylinder; D, the piston; the unshaded parts *o o* the leather collar, in the folds of which is placed the copper ring *p p*, distinctly seen but not marked in the figure; *m m* is the metal ring by which the leather collar is retained in its place; *n n*, the thin plate of copper or other metal fitted to the top of the cylinder, between which and the plate *m m* is seen the soft packing of tow, which we have described above, as performing the double capacity of oiling the piston and preventing its derangement.

4177.



The combination at *w x* represents the method of connecting the injecting tube to the cylinder; it may be readily understood by inspecting the figure; but in order to remove all causes of obscurity it may be explained in the following manner.

The end of the pipe or tube, which is generally made of copper, has a projecting piece or socket flange soldered or screwed upon it, which fits into a perforation in the side or base of the cylinder, according to the fancy of the projector, but in the figure before us the perforation is in the side.

The tube thus furnished is forcibly pressed into its seat by a hollow screw *w*, called a union screw, which fits into another screw of equal thread made in the cavity of the cylinder; the joint is made water-tight by means of a collar of leather, interposed between the end of the tube and the bottom of the cavity.

A similar mode of connection is employed in fastening the tube to the forcing pump, the description of which, although it constitutes an important portion of the apparatus, does not properly belong to this place; the principles of its construction and mode of action must therefore be supposed as known, until we come to treat of the construction and operation of pumps in general.

Admitting therefore that the action of the forcing pump is understood, it only now remains to explain the nature of its operation in connection with the hydrostatic press, the construction of which we have so copiously exemplified.

In order to understand the operation of the press, we must conceive the piston D, Fig. 4170, as being at its lowest possible position in the cylinder, and the body or substance to be pressed placed upon the crown or pressing table E; then it is manifest that if water be forced along the tube *b b b* by means of the forcing pump, it will enter the chamber of the cylinder F immediately beneath the piston D, and cause it to rise a distance proportioned to the quantity of fluid that has been injected, and with a force determinable by the ratio between the square of the diameter of the cylinder and that of the forcing pump. The piston thus ascending carries its crown, and consequently the load along with it, and by repeating the operation more water is injected, and the piston continues to ascend till the body comes into contact with the head of the frame B, when the pressure begins; thus it is manifest that by continuing the process the pressure may be carried to any extent at pleasure; but we have already stated, in developing the theory, that there are limits beyond which, with a given bore and a given thickness of metal, it would be unsafe to continue the strain.

When the press has performed its office, and it becomes necessary to relieve the action, the discharging valve placed in the furniture of the forcing pump must be opened, which will admit the water to escape out of the cylinder and return to the cistern, while the table and piston, by means of their own weight, return to their original position.

Friction of the Collar.—There had long been a lack of trustworthy information on the friction of the leather collars in hydraulic presses, until John Hick, C.E., of Bolton, carried out a series of valuable experiments, which furnished the following results;—

The friction increases as the pressure increases.

The friction of the leathers for rams of different diameters, if the pressure to the unit of area be the same, increases in direct proportion with the diameters, or with the square roots of the respective gross loads.

The depth of the leather does not affect the friction on the ram. In several of the experiments the leathers were cut after the first trial to half the depth, and after the second trial to one-quarter the original depth, and the results, in all three cases, were practically the same. This led to the belief that the water pressing against the sides of the ram produces a friction equal to that produced by the leather to the unit of area acted upon by the water. New cylinders were therefore tried, in which double the length of ram was opposed to the pressure, and the friction was again the same. It is thus evident that the depth of the leather and the length of ram in the cylinder have very little, or practically no influence on the total friction. In fact, it appears that the whole friction is produced just where the leather emerges from the hollowed part of the groove and begins to lean against the ram.

The experiments made with leather collars for a ram 4 in. in diameter, the leather being quite new and stiff and sparingly lubricated, show the greatest friction to be 1·55 per cent. of the pressure on the area of 12·56 sq. in., and the smallest friction as 1·07 per cent. If we take 1·5 per cent. for a 4-in. ram under these unfavourable circumstances, we are quite on the safe side. Forty-eight experiments made with leather collars used before, and well lubricated, give an average friction of 0·72 per cent. of the pressure on a ram of 4 in. diameter. In some of these experiments the friction was as high as 1 per cent., in others as low as 0·5 per cent., the variations being 0·5 per cent.

Thirty-four experiments with a ram 8 in. diameter show the friction to be, on an average, 0·395 per cent. of the pressure on the area of 50·26 sq. in. In some of these experiments the friction was as high as 0·52 per cent., whilst in others it was as low as 0·26, the variations being only about one-fourth per cent.

If we therefore take the friction of leather collars for hydraulic presses, or other hydraulic machinery in good working condition, as 1 per cent. for rams of 4 in. diameter, or as 0·5 per cent. for rams of 8 in. diameter, we may be certain that this will meet the generality of cases.

From the experiments is deduced the following formula;—$F = D \times P \times c$, in which F = total friction of leather collar; D = diameter of ram in inches; P = pressure to the square inch; C = a coefficient; $C = 0·0471$ if leathers new or badly lubricated; $C = 0·0314$ if leathers in good condition and well lubricated. Where the pressure is given to the circular inch the formula becomes;—$F = D \times P_o \times C_o$, in which F = total friction of leather collar; D = diameter of ram in inches; P_o = pressure to the circular inch; C_o = a coefficient; $C_o = 0·06$ if sparingly lubricated; $C_o = 0·04$ if well lubricated.

It may be well to select an example or two, in order to render the foregoing perfectly clear.

First Example.—The friction of a leather collar of a 12-in. ram with a pressure of 5000 lbs. to the square inch;—$F = 12 \times 5000 \times 0·0314 = 1884$ lbs. if well lubricated. The total pressure on a 12-in. ram is $= 113 \times 5000 = 565000$ lbs.; and the friction, as found above, $1884 \div 565000 = 0·0033$, or one-third per cent.

Second Example.—The friction of the leather of a 5-in. ram, with 6500 lbs. pressure to the circular inch;—$F = 5 \times 6500 \times 0·04 = 1300$ lbs. The total pressure on the 5-in. ram $= 25 \times 6500 = 162500$ lbs.; and the friction, as found above, $1300 \div 162500 = 0·008$, or eight-tenths per cent.

The annexed Table gives, in a compact and convenient form, the frictional resistance in percentage of the total hydraulic pressure for rams from 2 in. up to 20 in. in diameter.

D, Inches.	F, per Cent.	D, Inches.	F, per Cent.	D, Inches.	F, per Cent.	D, Inches.	F, per Cent.
2	2·00	7	0·57	12	0·33	17	0·23
3	1·33	8	0·50	13	0·30	18	0·22
4	1·00	9	0·44	14	0·28	19	0·21
5	0·80	10	0·40	15	0·20	20	0·20
6	0·66	11	0·38	16	0·25		

FRICTION OF LEATHER WASHER FOR RAM ½ IN. DIAMETER.

Leather Washer, new and stiff.			Leather used before.		Second Leather.	
Gross Load on Ram ½ in. diam.	Friction of Washer.	Friction in percentage of Gross Load.	Friction in lbs.	Friction in percentage.	Friction in lbs.	Friction in percentage.
lbs.	lbs.					
50	13	26·0	9·0	18·0	9	18·0
100	12·5	12·5	8·5	8·5	13	13·0
150	18	12·0	11·5	7·6	15	10·0
200	20	10·0	13	6·5	20	10·0
250	23	9·6	13·5	5·4	23	9·6
300	27	9·0	14·7	4·9	27	9·0
350	18	5·1	15·4	4·4	29	8·2
400	23	5·6	16·5	4·1	31	7·7
450	26	5·7	18	4·0	34	7·5
500	25	5·0	19	3·8	37	7·4
600	26	4·3	20	3·3	38	6·3
700	32	4·5	23·3	3·3	44	6·2
800	38	4·7	21	3·0	45	5·6
900	35	3·9	28	3·1	48	5·3
1000	33	3·3	33	3·3	48	4·8
1100	40	3·6	35·2	3·2	48	4·8
1200	50	4·1	40·8	3·4	50	4·1
1300					50	3·8

FRICTION OF LEATHER COLLAR FOR RAM 4 IN. DIAMETER. LEATHER NEW AND STIFF; SPARINGLY LUBRICATED.

Net Pressure on 4-in. Ram.	Equivalent Pressure a square inch.	Pressure on 4-in. Ram.	Friction of Leather in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs		
37	188·7	2,368	110	4·6
87·5	446·2	5,600	117	2·0
132	673·2	8,448	125	1·48
180	918	11,520	130	1·12
227	1157·7	14,528	171	1·17
273	1392·3	17,472	214	1·22
332	1693·2	21,248	228	1·07
377	1922·7	24,128	280	1·16
424	2162·4	27,136	334	1·23
475	2422·5	30,400	389	1·27
574	2927·4	36,736	459	1·25
668	3406·8	42,752	543	1·26
762	3886·2	48,768	611	1·31
865	4411·5	55,360	753	1·36
967	4931·7	61,888	823	1·33
1060	5406	67,840	1047	1·54
1150	5865	73,600	1147	1·55
Average percentage of 15 =				1·28

FRICTION OF LEATHER COLLAR FOR RAM 4 IN. DIAMETER. LEATHER WELL LUBRICATED.

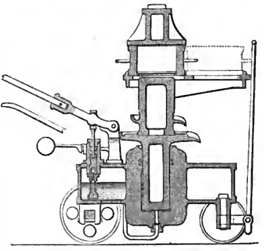
Depth of Leather touching Ram.			½-in.		¾-in.		⅝-in.	
Net Pressure on ½-in. Ram.	Equivalent Pressure a square inch.	Pressure on 4-in. Ram.	Friction of Leather in lbs.	Friction in percentage of Load.	Friction of Leather in lbs.	Friction in percentage of Load.	Friction of Leather in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs.						
41	209·1	2,624	56	2·13	37	1·40	39	1·50
87	443·7	5,568	70	1·25	52	0·94	70	1·25
135	688·5	8,640	80	0·95	78	0·91	80	0·92
180	918·0	11,520	84	0·72	100	0·87	85	0·73
227	1157·7	14,528	88	0·60	116	0·80	92	0·63
273	1392·3	17,472	93	0·53	162	0·92	105	0·60
321	1637·1	20,544	103	0·50	171	0·84	125	0·60
369	1881·9	23,616	123	0·52	189	0·80	140	0·59
419	2136·9	26,816	140	0·52	214	0·79	154	0·57
463	2361·3	29,632	156	0·52	226	0·76	168	0·56
562	2871·2	35,968	176	0·49	244	0·67	180	0·50
651	3320·1	41,664	231	0·55	280	0·67	231	0·55
755	3850·5	48,320	312	0·64	374	0·77	280	0·58
852	4315·2	54,528	335	0·61	420	0·77	305	0·56
952	4855·2	60,928	375	0·61	493	0·81	360	0·59
1052	5365·2	67,328	432	0·63	558	0·83	390	0·58
1150	5865·0	73,600	520	0·70				
1250	6375·0	80,000	660	0·75				
Average percentage of 16 =				0·61		0·846		3·706

FRICTION OF LEATHER COLLAR FOR RAM 8 IN. DIAMETER.

			Leather new and sparingly lubricated.		Leather used before, well lubricated.	
Net Pressure on ½-in. Ram.	Equivalent Pressure a square inch.	Pressure on 8-in. Ram.	Friction in lbs.	Friction in percentage of Load.	Friction in lbs.	Friction in percentage of Load.
lbs.	lbs.	lbs.				
87	443·7	22,272	102	0·46	94	0·42
135	688·5	34,560	162	0·17	145	0·42
180	918·0	46,080	207	0·45	180	0·39
227	1157·7	58,112	255	0·44	186	0·32
273	1392·3	69,888	321	0·46	216	0·31
321	1637·1	82,176	385	0·47	271	0·33
369	1881·9	94,464	415	0·44	274	0·29
419	2136·9	107,264	517	0·51	290	0·27
463	2361·3	118,528	569	0·48	355	0·30
562	2871·2	143,872	690	0·48	374	0·26
651	3320·1	166,656	866	0·52	433	0·26
755	3850·5	193,280	889	0·46	560	0·29
852	4315·2	218,112	1047	0·48	590	0·27
952	4855·2	243,712	1121	0·46	682	0·28
1052	5365·2	269,312	1320	0·49	862	0·32
1150	5865·0	294,400	1475	0·50	942	0·32
1250	6375·0	320,000	1600	0·50	1056	0·33
Average percentage of 17 =				0·474		0·316

Portable Hydraulic Press.—Fig. 4178 shows a section of an improved hydraulic hand-press, by Gwynne and Co., Essex Street Works, London. This press can be used for expressing oil from linseed, rape, cotton, colza, poppy, or other seeds, and is a very convenient arrangement, well suited for India and the colonies. The machine consists of a cylinder 7 in. diameter, with 1-inch ram. On the top of the ram is cast a receiver with a lip, into which the oil runs after being pressed out of the seeds. The top of the ram is also fitted with an arrangement for taking two boxes; much time is thus saved by filling one while the other is under pressure.

4178.

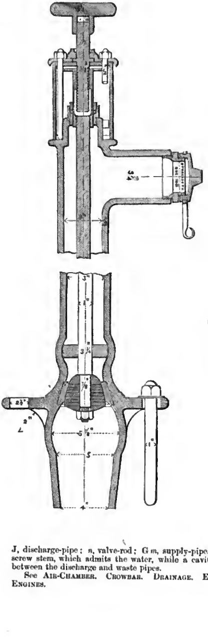


The ram is worked by a small hydraulic pump of gun-metal, fitted on to the tank, which also forms the base of the press. The pump is fitted with pressure-gauge and self-acting safety-valve; the lever handle is made in two pieces for convenience of travelling, and the machine is rendered portable by being erected upon a carriage fitted with wheels and handle. The weight of the whole is about 16 cwt.; it will give a pressure of about 60 tons, and, with one press-box, will press about 1½ bushel of seed an hour.

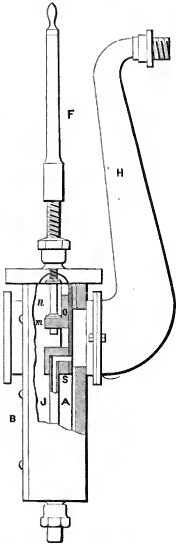
Hydrant.—A hydrant is a pipe or spout at which water may be drawn from the mains of an aqueduct; it is, in fact, a large water-plug. Fig. 4179 is a section of one of the hydrants used in the city of Brooklyn, U.S. Upwards of eight hundred hydrants are in use in that city, distributed over 120 miles of pipes. Although the diameter of these pipes varied from 6 to 36 in., 4-in pipes were exclusively used to connect the hydrants with the street pipes.

Fig. 4180 relates to a simply-constructed hydrant invented by Wm. Kearney, Union Township, N.J. A B is the case; O, a sliding disc-valve perforated at S; F, screw stem; H, the nozzle; J, discharge-pipe; *n*, valve-rod; G *m*, supply-pipe. The valve O is operated by means of the screw stem, which admits the water, while a cavity on the lower edge opens a communication between the discharge and waste pipes.

4179.



4180.



See Air-Chamber. Crowbar. Drainage. Engines, Varieties of. Pumps and Pumping Engines.

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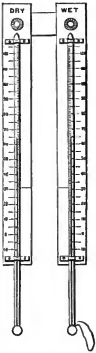
HYDROMETER. Fr., *Hydromètre;* Ger., *Hydrometer;* Ital., *Idrometro;* Span., *Hidrómetro.* See Saccharometer.

HYGROMETER. Fr., *Hygromètre;* Ger., *Hygrometer;* Ital., *Igrometro;* Span., *Higrómetro.*

A hygrometer is an instrument for measuring the degree of moisture of the atmosphere. It is principally used for meteorological purposes, but it is also of great service in determining the degree of humidity of the air in certain manufactories and in conservatories. The form of the instrument employed for this purpose is known as Mason's Dry- and Wet-Bulb Thermometer, Fig. 4181, which consists of two thermometers, as nearly as possible identical, the one marked dry, the other wet. The bulb of the wet thermometer is covered with thin muslin, round the neck of which and over the muslin is twisted loosely, or tied in a loose knot, a conducting thread of lamp-wick, common darning-cotton, or floss silk; this passes to an adjacent vessel of water placed at such a distance as to allow a length of conducting thread of about three inches. The reservoir of water should be placed on one side and a little beneath, so that evaporation from the water may not affect the reading of the dry bulb by its too near vicinity. Before use, the cotton lamp-wick should be washed in a solution of carbonate of soda, and pressed whilst under water throughout its length. In use it should be of such extent that the water conveyed be sufficient in quantity to keep the muslin on the bulb as moist as when the air is saturated with vapour. The amount of water supplied can be increased or diminished by increasing or decreasing the extent of the conducting thread. The temperatures of the air and of evaporation are given by the readings of the two thermometers.

4181.



ICE-MAKING MACHINE. Fr., *Congelateur;* Ger., *Eismaschine.*

Ice acts as a cooling agent in virtue of the physical fact that, in common with all solid substances, it requires an expenditure of heat for its conversion into the liquid state. The heat thus applied does not produce any elevation of temperature, but as the ice melts it disappears, so far as the indications of the thermometer will show, and there remains a quantity of water of the same temperature as the ice itself. Thus when ice or snow is mixed with three-fourths its weight of boiling water, the water remaining after the ice has melted has a temperature of 32° Fahr., the same as the ice itself; the quantity of heat in the boiling water, corresponding to the interval of temperature between 32° and 212° Fahr., having been rendered latent, or expended in effecting the liquefaction of the ice. It is in this way that ice cools water, air, or any other substance it is brought in contact with which has a temperature higher than 32° Fahr. Hence refrigeration is simply a manipulation of heat. It is an operation in this respect perfectly analogous to the production of a high temperature, in so far as both processes consist in the transfer of heat from one substance to another, and are subject to the same general laws. They are, however, reverse processes. Thus in generating steam, heat produced by the combustion of fuel is communicated to water. In making ice, on the contrary, heat is abstracted from water, and in this process the water which is cooled corresponds to the fuel burnt in generating steam, or in converting any other substance into vapour. Just in the same way that the fuel in burning yields its heat to the substance vaporized, so does the water, in making ice, yield its heat to some other substance capable of receiving it.

This is the nature of the work to be done in making ice, and it is now necessary to consider the amount of that work requisite for producing a given quantity of ice.

Water at the temperature of 60° Fahr. contains an amount of heat greater than that contained in an equal weight of ice at 32° Fahr. to the extent of 170·65 heat units for each pound, consequently to convert water at 60° Fahr. into ice, it is necessary to abstract that amount of heat from it. Thus to produce a ton of ice the quantity of heat to be abstracted from water at 60° Fahr. amounts to

Heat units. lbs.
$$382256 = 2240 \times 170 \cdot 65.$$

This is a quantity of heat not more than about one-eightieth part of that capable of being generated by the combustion of a ton of ordinary coal.

The means by which this amount of heat may be abstracted from water consist in producing some physical change involving an expenditure of heat, and doing this in such a way that the heat required for, and applied to that purpose, is abstracted from the water to be cooled and frozen. The conversion of any substance into vapour is a change of this kind, which involves an expenditure of heat similar to that taking place in the melting of ice. The amounts of heat thus absorbed by various substances in vaporizing are as follows;—

	Latent heat a lb. Heat units.	Authority.
Water	966·1	Regnault.
Liquid ammonia	900·0	Favre and Silbermann.
Alcohol	364·3	Andrews.
Ether	162·8	

The amount of heat thus disposed of and rendered latent in the formation of steam from water is considerably greater than that existing in the latent condition in liquid water, or, what amounts to the same thing, that expended in melting ice; but the vaporization of water cannot be applied as a means of refrigeration to any great extent, because under the ordinary atmospheric pressure it does not take place readily or with sufficient rapidity at temperatures much below the normal boiling-point, or 212° Fahr., and even when the pressure is removed by means of an air-pump, the vaporization of water proceeds very slowly at low temperatures. There are, however, other substances which vaporize readily under these conditions; and, for this reason, they are specially suited for artificial refrigeration, although the amounts of heat expended and rendered latent in their vaporization are less than in the case of water. Ether, alcohol, and liquid ammonia are substances of this kind; and, according to the foregoing data, expressing the latent heat of their vapours, the quantities of each of these substances which would have to be vaporized, in order to produce a ton of ice from water at 60° Fahr., or to produce a refrigeration equivalent to the melting of a ton of ice, would be;—

	lbs.
Ether	2348·009
Alcohol	1049·272
Liquid ammonia	424·728

From this comparison it will be seen that the expenditure of heat accompanying the vaporization of liquid ammonia is much greater than it is in the case of alcohol or ether, and that in this respect it is the most powerful as a refrigerating agent. But the amount of heat rendered latent in the vaporization of any substance is not the chief point which determines its efficiency as a refrigerating agent. The degree of facility with which a substance vaporizes at low temperatures is of still greater importance, as will be evident from the following Table, which gives the tension of the vapours at different temperatures below the boiling-points of the liquids under normal atmospheric pressure.

		Ammonia.	Ether.	Alcohol.	Water.
Normal Boiling-point.		28°	95°	172°	212° F.
Tension of vapour in inches of mercury at	° Fah.	inches.	inches.	inches.	inches.
	104	463·64	35·81	5·26	2·16
	68	254·61	17·06	1·75	·68
	50	181·58	11·28	·96	·36
	32	124·52	7·22	·50	·18
	− 4	55·03	2·66	·13	
	− 40	20·81			
	− 109	9·45			

Since the tension of a vapour at any temperature is the measure of the facility with which the liquid evaporates at that temperature, it will be seen from the data in this Table that in this respect there is a very considerable difference between the liquids there named. Here, again, the characters of liquid ammonia are such as to give it a marked precedence over all the other liquids, as a refrigerating agent, by reason of its relative capability of vaporizing at very low temperatures. This substance is in fact gaseous under normal pressure, within the ordinary range of atmospheric temperature, the boiling of the liquid being many degrees below the zero of Fahrenheit's scale; and at ordinary temperatures it requires a pressure of from eight to ten atmospheres—117 to 150 lbs. a square inch—to maintain it in the liquid state.

Alcohol, although it has a greater capability than ether of absorbing heat in vaporizing, is still inferior to ether as a refrigerating agent, on account of its being much less readily vaporized at low temperatures; and even ether evaporates so slowly at temperatures much below its normal boiling-point, that it can be used for refrigerating only with the aid of an air-pump to maintain the requisite rate of vaporization.

Liquid ammonia is therefore by far the most efficient material to use for this purpose, not only on account of its ready vaporization at low temperatures, but also because its power of absorbing heat in that change is but little inferior to that of water.

Another process, in which heat is expended and rendered latent, is the expansion of air. The amount of heat thus absorbed is at the rate of ·069, or about $\frac{1}{14}$th of a heat unit for each pound of air expanded to the extent of ·002035, or about $\frac{1}{491}$th of its volume at 32° Fahr. under normal pressure. If therefore air be compressed, say to one-tenth of its bulk, and, after being cooled to a low temperature, it be allowed to expand in such a way as to perform mechanical work, such as moving a piston, there is an expenditure of heat proportional to the resistance overcome and to the degree of expansion. Consequently the temperature of the gas is reduced during the act of expansion, and this effect may be taken advantage of for purposes of refrigeration. The chief disadvantage of this method consists in the great expenditure of power requisite for compressing the air, which involves a large consumption of fuel.

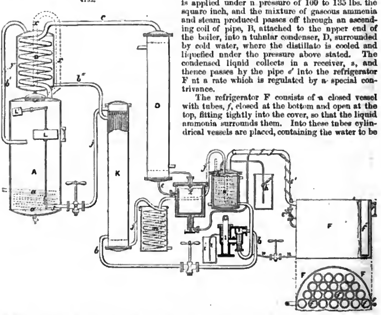
From what has been stated, it will be apparent that at present the choice of a refrigerating agent for producing ice or great degrees of cold lies between ammonia, ether, and air, and that ammonia presents the greatest advantages for this purpose.

The expansion of compressed air appears to have been the means first adopted for making ice, by Dr. Gorrie, of America; and in this country ether was the material employed in one of the earliest ice-making machines invented by Harrison, in 1856.

The fundamental principles on which this apparatus was constructed were correct, but there appears to have been several serious errors made in their application, and the plan did not come into use in this country. The ether machine was afterwards improved by Messrs. Siebe in 1862, and they have since employed themselves specially to the manufacture of these ice machines. Most of those which have been made were for India and other hot climates, where it has been found more advantageous to make ice by artificial refrigeration than to import it from America, owing to the large amount of waste by melting during the voyage through warm latitudes.

In the year 1860 another apparatus was invented by M. Carré, of Paris, in which a very strong solution of ammonia was used as the refrigerating agent. The arrangements of this apparatus provided for the condensation of the ammonia vaporized in the refrigerator, in such a way that it was used over and over again, and the operation of the apparatus was continuous, as in the case of the ether machine. Fig. 4182 represents this apparatus. A strong, vertical boiler, A, is charged with a concentrated solution of ammonia, to which heat is applied under a pressure of 100 to 135 lbs. the square inch, and the mixture of gaseous ammonia and steam produced passes off through an ascending coil of pipe, B, attached to the upper end of the boiler, into a tubular condenser, D, surrounded by cold water, where the distillate is cooled and liquefied under the pressure above stated. The condensed liquid collects in a receiver, s, and thence passes by the pipe c′ into the refrigerator F at a rate which is regulated by a special contrivance.

4182.



The refrigerator F consists of a closed vessel with tubes, *f*, closed at the bottom and open at the top, fitting tightly into the cover, so that the liquid ammonia surrounds them. Into these tubes cylindrical vessels are placed, containing the water to be frozen. The upper end of the refrigerator is connected by means of a pipe, G, with a vessel, H, within which the gaseous ammonia discharged from the refrigerator comes in contact with a continuous supply of cold water, and is thereby absorbed, while the solution of ammonia produced is removed from the bottom of the vessel H by the pump I. In this way the gaseous ammonia is removed from the refrigerator and the pressure kept so low that the liquid ammonia is vaporized continuously, thereby abstracting heat from the contents of the tubes *f*.

The solution of ammonia produced in the absorber H is forced by the pump I through the pipe *b* into the outer casing of a tubular vessel, K, called the regenerator, through the tubes of which hot water exhausted of ammonia flows in the opposite direction from the boiler A. Here an interchange of temperature takes place, the solution of ammonia becoming heated while the exhausted liquor is cooled. The solution of ammonia thus heated then passes on into the closed vessel above the boiler and containing the coil B, where it is still further heated, while the gaseous ammonia and steam within the coil B are partially cooled and condensed, and it then flows by the pipe *b'* into the boiler A, to serve for a repetition of the process.

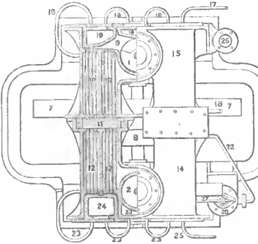
The hot liquor exhausted of ammonia meanwhile flows from the boiler in a regulated current through the pipe J into the tubes of the regenerator K, thence through a cooling worm, *m*, surrounded by water, where its temperature is sufficiently reduced, and then passes into the absorber H, furnishing the supply of water for dissolving the ammonia as already described.

This machine has been largely used in the south of France for effecting the crystallization of salts by cooling, and several have been sent out to India for making ice.

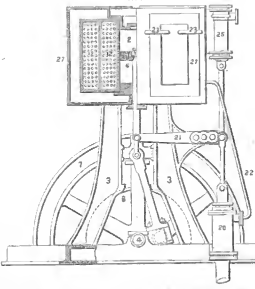
In 1862 A. C. Kirk invented a machine in which the alternate compression and expansion of air was applied as the means of refrigeration. The arrangement of the machine was very good; but for making ice it was expensive, on account of the relatively large expenditure of power required. Kirk has, however, recently introduced another form of his machine, which seems better adapted to refrigerate economically.

Fig. 4183 is a plan partly in horizontal section, Fig. 4184 an end elevation partly in vertical section, of this improved apparatus. It comprises two vertical cylinders 1, 2, each formed in the same casting, with casings containing accessory spaces and passages, and mounted in an inverted position on frame standards 3 over the crank shaft 4, by which their pistons 6 are actuated through connections of a common kind. The shaft 4 is fitted with a fly-wheel 7 and with a pulley 8, the latter receiving a driving belt from a convenient prime mover. The cylin-

4183.



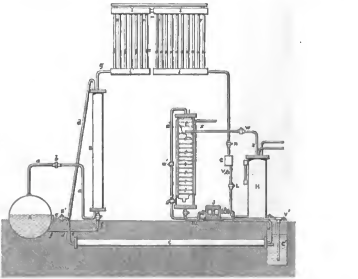
4184.



ders 1, 2, have ports at both ends, and one half of Fig. 4183 represents the section as at the level of the lower ports, but only the port 9 of one cylinder 1 is seen, as the lower port of the other cylinder 2 is at the other side. From the bottom of cylinder 1 the air can pass through the port 9, thence through a set of tubes 10 to a regenerator 11, the other side of which communicates through a second set of tubes 12 with a space 13 having at its upper end a port leading into the top of the other cylinder 2. This space 13 is very narrow at the level of the section, but increases in width upwards. The bottom of cylinder 2 communicates through similar parts in the casings 14, 15, with the top of cylinder 1. The spaces crossed by the tubes 10 and those in the casing 15 are occupied and traversed by the water or other liquid used to abstract heat from the compressed air, such water entering by a pipe 16, and being discharged by a pipe 17, first however being led by means of pipes 18 through spaces 19 formed at the outer sides of the cylinder ports 9. A pump 20 worked by a lever 21 connected to one of the piston-rod slide-blocks is used for forcing the liquid to be cooled through the apparatus, and this liquid passes by a pipe 22 into the casing 14 crossed by tubes, passing thence to the space crossed by the tubes 12, and through pipes 23 and spaces 24 to the outlet-pipe 25, it being preferable to employ in the apparatus air which in its most expanded state therein is of a greater than atmospheric pressure. A force-pump 26 is provided for forcing in air to compensate for any leakage, being arranged to be worked by means of a lever connected to one of the piston-rod slide-blocks. The pipes for leading the air from the pump to the interior of the apparatus are not shown, but may be arranged in any convenient way in communication with the top and the bottom of either cylinder, provision being made as usual for drying the air so forced in. The cylinder 2 and the parts in connection with it in which the compressed air expands are shown in Fig. 4184 as enclosed in an outer casing 27, to prevent as far as possible the communication of heat from the atmosphere, and the jacket space enclosed by this casing is to be filled with any suitable non-conducting substance.

An improved form of the ammonia apparatus, which comprises some novel features of very great importance in regard to the use of that material for refrigeration, was invented by Mr. Reece in 1867. The arrangement of this apparatus is shown by Fig. 4185. The boiler A is charged with water or a very weak solution of ammonia, and the steam, discharged under a pressure of 100 lbs. to the square inch, passes by the pipe *a a* to the bottom of a Coffey's analyzer B, consisting of a tall columnar vessel with a series of plates arranged one above the other inside. Into the top of this vessel a concentrated solution of ammonia is pumped continuously, and in descending from plate to plate it meets the ascending current of high-pressure steam, the effect of their contact being to convert the ammonia into gas, while the steam is condensed and flows back again to the boiler A. The gaseous ammonia passes out of the analyzer by the pipe *g* into a tubular rectifier D D, where the remaining steam is condensed and separated, while the ammonia passes on through a condenser F F, where it is liquefied, and then flows through a pipe to the refrigerator H, the supply being regulated by a cock *n*.

4185



Meanwhile a regulated current of spent liquor passes from the boiler into a long tube, C, called the heater, fitted with an internal set of tubes, through which the concentrated solution of ammonia is forced by the pump J into the top of the analyzer. By this means the solution of ammonia is heated, and at the same time the hot liquor from the boiler is sufficiently cooled to be supplied to the absorber I, into which it is forced by the pressure of the boiler, through the pipe *x*, fitted with a cock *w*, to regulate the supply. In the absorber I this water becomes saturated with gaseous ammonia discharged from the refrigerator H, and the resulting strong solution of ammonia is then pumped out into the analyzer.

The important feature of this arrangement consists in the application of the analyzing column B, and the rectifier D D, by which it is intended that the dehydration of the ammonia should be carried so far that the condensed liquid passing into the refrigerator may be practically free from water, while in Carré's apparatus the liquid supplied to the refrigerator contains 25 per cent. of water, and only 75 per cent. of actual ammonia.

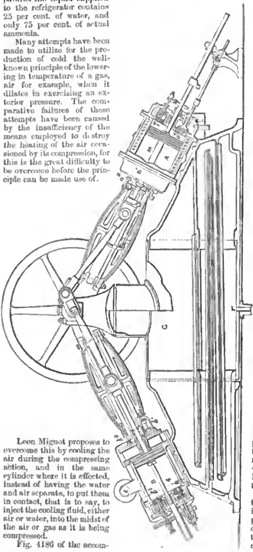
Many attempts have been made to utilize for the production of cold the well-known principle of the lowering in temperature of a gas, air for example, when it dilates in exercising an exterior pressure. The comparative failures of these attempts have been caused by the insufficiency of the means employed to destroy the heating of the air occasioned by its compression, for this is the great difficulty to be overcome before the principle can be made use of.

Leon Mignot proposes to overcome this by cooling the air during the compressing action, and in the same cylinder where it is effected, instead of having the water and air separate, to put them in contact, that is to say, to inject the cooling fluid, either air or water, into the midst of the air or gas as it is being compressed.

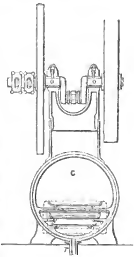
Fig. 4186 of the accompanying drawings is a longitudinal section of Mignot's ice-making machine; Figs. 4187, 4188, transverse sections; and Fig. 4189 an enlarged section of the compression cylinder A.

The air receptacle G forms the base of the whole machine; it supports at its ends the compression cylinder A, and the expansion cylinder B, and at the centre the supports of the crank-shaft O, the centre por-

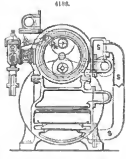
4186



4187.

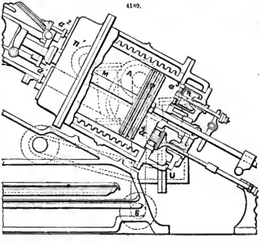


4188.



tion of which receives the rods of both cylinders. Each of the cylinders is double-acting, that is to say, they aspire and throw back from both sides of their pistons P and Q; they are provided with valves a^1, a^2, a^3, a^4, serving for the suitable distribution of air for the compression cylinder A, and b^1, b^2, b^3, b^4, for the expansion cylinder B. The valves are formed of metal discs provided with a copper ring, cut in such a manner as to close the orifice, following a circumferential line of contact. The valves are worked by rods actuated by forked arms, commanded in the case of the compression cylinder by butting-pieces fixed to the piston-rod, and in the case of the expansion cylinder by eccentrics fastened on the main shaft. The compression cylinder A draws the air through its two aspiration valves a^1, a^2, and throws it out through its two other valves a^3, a^4; against this cylinder the injection arrangement is fitted for the cooling of the air in proportion to its compression. It is simply composed of a pump M, the piston *m* of which, actuated by a rod united to the principal crank, sends the cold water through one of two pipes *n* and n^1 into the part of the cylinder where the compression takes place. The mixture of compressed air and water without being heated proceeds by one of the outlet-valves a^3 or a^4, and enters into the receptacle S, which forming a siphon serves to effect the separation of the fluids through the water falling to the bottom. The air being retained at the upper part of the receptacle is allowed to escape through a valve or port and pipe, which leads it to the lower part of the receiver G. The water on the other hand descends into a reservoir U, where it finds its level; the excess falls into the air receiver through an orifice situated at its side. The receiver is provided with inclined plates forming a zigzag course or passage, in which the two fluids, air and water, circulate in a contrary direction; the air rising to the upper part of the chamber and kept in reserve to be taken by a pipe which leads it to the expansion cylinder B, whilst the water which has passed through the pipe in U flows downwards towards *r*, and leaves the receiver finally, or is again returned to the apparatus by an injection-pump. The expansion cylinder B draws the air from the receiver G through the pipe communicating with the two outlet-valves b^1, b^4. The refrigerated air leaves the cylinder through one of the outlet-valves b^2, b^3, and passes into a pipe *c*, from whence it is led into the medium or place to be cooled or frozen.

4189.



With this arrangement of mechanism the lowering of the temperature may be carried to any desired extent by taking a portion of the cold air produced in order to cool the injection-water, or even by directly compressing this cold air in the compressing cylinder A.

It will be seen that in consequence of the inclination of the two cylinders A, B, and of the junction of the cranks of their respective pistons P and Q upon the same shaft O, the compression and expansion take place simultaneously, the second action aids the first which gives the resisting force and develops the frigorific disposition already attained.

This article is taken, with some addition, from an excellent paper in the Quarterly Journal of Science, on the Artificial Production of Cold, by Dr. B. H. Paul.

IMPACT. Fr., *Choc*; Ger., *Stoss*; Span., *Empaquetár*.

The word impact implies contact or impression by touch; collision; force communicated. More particularly impact is the single instantaneous blow or stroke of a body in motion against another either in motion or at rest.

IMPETUS. Fr., *Mouvement*; Ger., *Grösse Bewegung*; Ital., *Impeto*; Span., *Impetu*.

Impetus is the force with which any body is driven or impelled; or its momentum.

INCLINED PLANE. Fr., *Plan incliné*; Ger., *Schieft Ebene*.

See Mechanical Powers.

INCRUSTATION OF BOILERS. Fr., *Incrustation des chaudières à vapeur*; Ger., *Kesselsteinbildung*.

Undistilled water generally contains in solution a quantity of sulphate of lime, gypsum, and limestone, chalk, as well as smaller quantities of other substances. Certain waters also contain acid particles which destroy very rapidly metallic vessels used for evaporation.

If water is evaporated in a boiler, the solid substances which the water contains in solution are not evaporated with it, and it will be found that the water becomes more and more saturated as the calcareous salts are deposited upon the metallic walls. If these deposits are not removed they will finally become solidified and form upon the walls of the boiler a crust, the thickness as well as the hardness of which increases as frequently as the water is renewed, and it then becomes necessary to use for its removal scaling hammers and chisels. A steam-boiler covered on its interior with a crust of solid deposits termed scale, has its evaporating power diminished by the reduced inductibility of the plates, and is exposed to the greatest dangers of explosion. In fact, any plate covered on the interior side with a substance which arrests the prompt transmission of heat, may be heated on the exterior side to a red heat, which will necessarily diminish the resistance of the metal by increasing the oxidation, thus reducing rapidly the thickness of the plate.

The disadvantageous consequences will be increased as the interior space of the boiler is diminished, so that in boilers with tubes, the scale may often be accumulated to such an extent that the space between the tubes may be entirely filled. If it now happens that the water finds its way through cracks in the scale between the latter and the decayed and almost red-hot plate, a sudden formation of steam takes place, which detaches the scale over an extended length, exposes a great part of the red-hot plate to a much higher temperature than that of the evaporation, and finally brings the water of the boiler in contact with the superheated plates; the consequence is the sudden production of a great volume of steam, causing almost inevitably an explosion.

Admitting that this extreme case does not very frequently happen, the accumulations of solid deposits and of a great thickness must, nevertheless, eventually bring about the destruction of the boiler, and will in all cases reduce its steam-raising power. It is therefore of the greatest importance to prevent the incrustation of a boiler by arresting solidification of the deposits, if that is possible, or at least by cleaning the boiler before the scale has attained a certain thickness.

The means employed for preventing incrustation are;—

Frequent extraction before solidification, and repeated cleanings;

The addition of substances capable of preventing the adhesion to the plates;

The addition of substances which form a chemical combination with the calcareous salts and modify their properties; and

Feeding with water previously purified.

Mechanical extraction of the deposits and frequent cleaning of a boiler are the means most generally adopted, independently of the nature of the deposits, for preventing incrustation. The operations should be repeated as often as required by the calcareous composition of the water used for feeding the boiler.

The extraction of the deposits, at least of the liquid portion of them, may be effected by means of special tubes designed for the purpose; the solid scale fixed to the plates of the boiler or heating tubes, especially at the places exposed to great heat, can only be removed by striking them with a scaling hammer after the boiler has been emptied. If moderately pure water is used for the boiler, extraction and cleaning are sufficient, but the cleaning should be repeated frequently, so that the deposits are not allowed to get hard; should, however, a few solid deposits remain behind, the hammer has then to be used, and with this view, the diameter of the boiler should be arranged so as to allow admittance of a man or boy.

Care should, however, be taken to empty the boiler only when cold, otherwise the furnace of the boiler, still very hot, calcines the residue after the water has been let off, and it becomes then very difficult to remove.

It is therefore indispensable that no part of a boiler should be inaccessible to necessary tools for separating and removing the deposits; it is of equal importance that the parts in direct contact with the hearth should present no marked projection or deepening in which the calcareous products could accumulate, get hard, and become almost immediately separated from the liquid. Such is especially the case in the joints of the fire-box of locomotives and in other steam generators of a similar construction, where care is taken to fix plugs which may be removed when desired in order to introduce tools through the holes for the raising of the deposits.

Substances hindering the adhesion of Deposits.—If the water used contains a high percentage of calcareous salts, and if frequent cleaning of the boiler does not prevent the formation of scale, it becomes necessary to adopt special means to diminish the inconvenience.

The following remedies have, among others, been used with varying success to prevent incrustation;—

1. Potatoes, $\frac{1}{50}$th of weight of water prevents adherence of scale.
2. 12 parts salt, 2½ caustic soda, $\frac{1}{4}$th extract of oak bark, ½ potash.
3. Pieces of oak-wood suspended in boiler and renewed monthly.
4. 2 oz. muriate of ammonia in boiler twice a week.
5. A coating 3 parts of black-lead, 18 tallow, applied hot to the inside of the boiler every few weeks.
6. 12½ lbs. of molasses fed into an 8-horse boiler at intervals, prevented incrustation for six months.
7. Mahogany or oak saw-dust in small quantities. Use this with caution, as the tannic acid attracts iron.
8. Carbonate of soda.
9. Slippery elm-bark.
10. Chloride of tin.
11. Spent tanners' bark.
12. Frequent blowing off.

Preliminary Purification of the Feed-water.—There is no better means of preventing incrustation than to feed the boiler, where circumstances permit, with water already purified and free from all calcareous salts or corrosive acids.

There are two ways of obtaining this result; preliminary distillation, and chemical operation.

If the water destined for the feeding of a boiler had to be always distillated, the expenses for fuel would be doubled; this plan has therefore to be abandoned, unless the waste heat of the boiler-furnace can be utilized for the purpose.

This has been tried in many cases; the first or preliminary heating of the water being effected in auxiliary recipients or vessels of less importance than the boiler, and which are not exposed directly to the fire upon the grate. The incrustation in these vessels will therefore be less strong than in the boiler.

The importance of the deposits could also be much diminished by the condensation of the steam used in the engine, upon cold surfaces in order to make it again applicable for the feeding of the boiler by adding only the small quantity of water necessary to make up for evaporation which had been condensated in reservoirs plunged into the sea outside the ship; this plan was tried and at first succeeded: it happened, however, that these reservoirs became covered on their outside with a deposit of scale from the salt water, in consequence of which their conductibility was much reduced.

In France M. Lelong-Burnet has introduced a method of purifying feed-water, which consists of a preliminary mixing of the water with chemical agents producing a precipitation of all the substances forming incrustation, so that only pure water reaches the boiler. He employs for that purpose special reservoirs provided with stirring apparatus in order to effect the mashing of the chemicals cast into the water in suitable proportions; the existing salts are thus dissolved and others formed which precipitate to the bottom of the vessels.

It will be seen that the application of the process makes a previous careful analysis of the feed-water indispensable, in order to select, according to its composition, the reacting agents which are best for the complete precipitation of the salts in solution. Burnet has made for that reason a great number of experiments in order to ascertain the most suitable agents for attaining the desired end, and to find the proportions which have to be used according to the nature of the feed-water. He has proposed for the purpose a great number of agents, and especially the solutions of caustic potash and soda, those of alkaline carbonates, baryta, strontianite, and so on. See Corrosion.

INDIA-RUBBER. Fr., *Caoutchouc*; Ger., *Kautschuk*; Ital., *Gomma elastica*; Span., *Cautchuc*.

India-rubber, known generally as caoutchouc, is composed of carbon and hydrogen, eight equivalents of the former uniting with seven of the latter. This compound is represented by the formula C_8H_7. When perfectly pure, it is solid, white, and transparent. Its specific weight is 925, that of water being 1000. At a temperature varying from 75° Fahr. to 95°, it is supple and elastic; and its surfaces, if free from all foreign matter, or recently cut, adhere and become united when placed in contact under a certain pressure. The physical properties of caoutchouc are greatly modified when its temperature is brought below 32°; it then undergoes a considerable contraction, it becomes less supple, only slightly adhesive, and hardly susceptible of extension. These changes of properties remain even after the temperature has been raised again to 60° or 70°. If a piece of caoutchouc be stretched and cooled down to 32°, it will remain in its extended state, even after its temperature has been raised again to 70°. Its primitive characteristic qualities suddenly return, however, when its temperature is raised above 95°. To make the experiment, take a strip of caoutchouc, stretch it, and place it for a few minutes in water at 32°; on taking it out of the water it will remain in its extended state and possess but very little elasticity at ordinary temperatures. But if it be plunged in water at 105° or above, it will immediately resume its original dimensions and all its elasticity. A strip of caoutchouc suddenly stretched manifests a sensible increase of temperature if placed in immediate contact with the lips. Sudden contraction, on the contrary, causes a diminution of temperature. The reason of this is that in the former case the stretching lessens the volume of the strip, whilst in the latter the volume is increased by the strip returning to its primitive dimensions.

Several liquid carburets of hydrogen, obtained from coal-tar by distillation—particularly benzine—expand and partly dissolve caoutchouc; the same effects are produced by essence of turpentine, deprived of water by quick-lime, and rectified by distillation. Pure essence of lavender and sulphuret of carbon are still more effective. The fat oils may dissolve a small quantity of it, especially when hot. Water and alcohol, which were believed formerly to have no effect upon it, exert a special action and precipitate it in part from its solution in sulphuret of carbon.

Liquid and gaseous chlorine hardly affect caoutchouc, and it is equally insensible to the action of hydrochloric acid, all the weak acids, the greater part of the gases, and the solutions of potash and soda. The concentrated sulphuric and nitric acids change it rapidly, especially when they are mixed, $SO_3, HO + NO_5, HO$.

The effect of steam upon caoutchouc is to soften it and greatly diminish its tenacity. When heated dry from 95° to 250°, it gradually loses its consistency; its particles become more and more susceptible of agglutinating together. At a temperature of about 290° to 330°, it is viscous and adheres to hard and dry substances; a large portion, however, of its consistency and elasticity is regained after cooling. From about 355° to 390° it fuses and appears to undergo an isomeric modification; for while its elementary composition remains unchanged, it has become sticky; if heated still more, up to 430° to 450°, it becomes oily, very brown, and suitable for protecting iron and steel from rust.

Caoutchouc, in contact with a substance in a state of ignition, burns with a luminous red and smoky flame. When subjected to distillation, it gives different carburets of hydrogen, two of which are isomeric with olefiant gas (caoutchene, hevëene); several others have an elementary composition, similar to that of essence of turpentine; they boil at various degrees—57°, 91°, 340°, 419°; most of them dissolve small pieces of dry caoutchouc.

The caoutchouc of commerce is composed of two principal parts, one possessing greater cohesion among its molecules, and being more tenacious and capable of resisting all agents; the other softer, ductile, adhesive, and more soluble. Each of these two parts offers the same elementary composition represented by the formula C_8H_7; the mass thus constituted contains fatty matters, an essential oil, coloured matters, three nitrous substances, water in variable proportions, which may be as great as 26 per cent., and traces of saline matters.

No one of these substances possesses the extensible and elastic properties in the same degree as the whole together; this seems to be due to the adhesion between the surfaces of the fibrous parts which are lubricated by the fatty matters, and to the isolation of the soft and soluble portion, which would render the whole mass more supple. The structure and composition of caoutchouc enable us to explain several phenomena concerning the penetration of sulphur, the vulcanizing of caoutchouc, and the slow or rapid changes in vulcanized caoutchouc.

In course of time, especially when exposed to the light and to a high temperature, caoutchouc undergoes changes, the effects of which may be seen, though their consequences on the immediate composition of the substance have not yet been determined; in such cases it exhales a sharp odour, it becomes softer and less tough, and sometimes even it may be easily broken.

Caoutchouc and some of its ruder uses were known long ago in South America and in India. In 1736, La Condamine, of the Institute of France, who had been sent to Peru with Bouguer for the purpose of making certain astronomical studies, sent the first specimen of this substance to the Academy of Science of the Institute. Fresnau and Macquer in 1751 and 1768 sent to the Academy some specimens of caoutchouc grown at Cayenne. It was not till the end of the last century that caoutchouc was first imported into England, where it became known under the name of india-rubber, from the almost sole use to which it was for a long time put of rubbing out lead-pencil marks.

In 1790, the raw material cut up into strips began to be used to make elastic balls, ligatures, and certain kinds of springs. Later methods of softening caoutchouc and spreading it over coarse fabrics to render them waterproof were discovered. Fourcroy succeeded in causing it to swell and partially dissolve by means of ether. Grassart in 1791 first made tubes of caoutchouc by winding long strips of that material helically upon slightly conical glass moulds, and joining the whole together. Nadler in 1820 invented a method of cutting caoutchouc into threads suitable for weaving into elastic tissues, and about this time Thomas Hancock introduced the use of the devil or masticator into the manufacture of caoutchouc. This machine, together with his after inventions, were the principal means of extending the india-rubber trade to the dimensions it has now attained.

A few years later, Mackintosh improved the manufacture of single and double waterproof fabrics by interposing a layer of caoutchouc rendered plastic by means of essence of turpentine; he gave a great impulse to the manufacture of overcoats of this material, which overcoats still bear his name. Towards the year 1830, Rattier and Guibal wove fabrics of caoutchouc threads deprived of their elasticity by means of a low temperature; by afterwards heating these fabrics up to about 105°, elasticity was restored to the threads. This method is still employed.

Hayward's patent, taken out on the 24th of February, 1839, by Goodyear, his representative, marks the first use of a small quantity of sulphur; but he did not state either the proportion or the temperature requisite for the transformation. In 1844, Goodyear described the properties—partly discovered in 1839—which sulphur gives to caoutchouc by uniting with it; from this time the operation was known as *vulcanizing*. The same year, Hancock succeeded in vulcanizing caoutchouc by means of a bath of sulphur.

The preparation and vulcanizing of caoutchouc were further improved by Rattier and Guibal. Parkes in 1846 invented the method of vulcanizing by immersing the manufactured articles in sulphuret of carbon containing $\frac{1}{40}$ (or 2½ per cent.) of protochloride of sulphur. Several manufacturers applied this method in various ways, and produced a great number of useful articles. M. Guibal, out of a mixture of caoutchouc and silicate of magnesia, formed cylinders, from which thick washers are cut to be used between the stuffing in stuffing boxes. Recently M. Gérard has constructed an ingenious machine capable of cutting 150 prismatic threads at once instead of eight or ten as formerly.

We will now describe the chief processes employed in manufacturing various articles of caoutchouc. When the methods of extracting the raw material in the countries where it is grown shall have been improved, we shall no doubt be able to obtain directly thick and homogeneous squares and cylinders free from foreign matter. It will then be easy to cut up, by means of machinery, these raw products into thin strips and fine threads, from which a great number of articles may be made much more durable than those prepared by working up the caoutchouc, because in that case the natural texture would not be injuriously changed by exposure to a high temperature.

Threads of pure Caoutchouc.—The irregular bottles of the raw caoutchouc of Para, softened in hot water and then cut in two and flattened between cast-iron plates heated up to 212°, are cut up by a circular knife worked by machinery into discs; these discs are fixed upon an axis, which as it revolves presents the disc to the edge of a circular knife. By this means it is cut up spirally into a long strip of any required thickness, and wound upon a reel. A small jet of water assists the action of the knife. A simple mechanical contrivance controls the action of this circular knife by displacing the centre of rotation and accelerating the motion as the circumference of the disc diminishes. The strip is afterwards subdivided simultaneously into five or six threads by being passed between from six to twelve double circular blades cutting in the manner of shears. This action is likewise assisted by the continuous flow of a small jet of cold water. A boy on the other side gently pulls the threads towards him, and thus assists the passage of the strip.

The thread obtained by this process is, in general, the most elastic and durable that can be obtained. It is first stretched, and its elasticity removed by means of a reduced temperature, in order that it may be more easily woven; contraction and elasticity are afterwards restored to the threads of the finished fabric by heating it in a stove up to 112°. These threads of pure caoutchouc possess the defect of becoming hard when exposed to cold and soft when exposed to heat, and for this reason vulcanized caoutchouc is generally preferred.

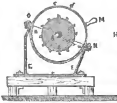
Various Operations performed on the Raw Material.—One of the first operations which caoutchouc is made to undergo consists in steeping it twelve to twenty-four hours in warm water; then, after having cut it up into pieces of about an inch thick with a long sharp knife, these irregular pieces are passed successively between two large rollers of about 15 in. in diameter moving at different rates of speed, one making one revolution and the other two-thirds of a revolution a minute, while a jet of water falls continuously upon the upper roller. In this way the pieces of caoutchouc are crushed, rolled, and at the same time pressed out unequally in the two directions; they issue as thin, granulated strips, full of little holes, thus presenting a large surface to the action of the weak solutions of soda and the hot water by which they are purified and rinsed, the air which dries, and the various mechanical and chemical agents which agglomerate, distend, or dissolve them; such, for example, as the deviling machine, hydrocarburets and sulphuret of carbon, the application of which we will describe later. The bottles or hollow cones of raw caoutchouc are left to soak in the warm water for three hours, and then taken out and cut asunder by means of a circular knife which is kept constantly watered. This watering is necessary whenever caoutchouc has to be cut, to counteract the adhesive property of the material and prevent an increase of temperature which would result from the friction, and which would increase the tendency of the caoutchouc to stick to the knife. The bottles when thus cut open let out into the water, into which they are again plunged, the earthy matters they may have contained.

For the raw caoutchouc of Brazil, which is less impure than the other kinds, cleansing by water alone is usually sufficient; it is then passed between the toothed cylinders, which reduce it to thin sheets full of holes.

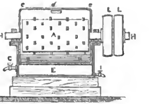
The *agglomeration* of the caoutchouc, introduced by Hancock, is an operation forming the basis of a great number of the preparations which we shall presently describe, and is effected in the following manner;—

The thin strips, obtained by the rolling already described, having been well washed and dried in the air, are made up into a packet or bundle weighing 14 kilogrammes or about 30 lbs., including the scraps and other work from the preceding operations, and heated in a stove up to about 95°. This bundle is then passed between a massive iron cylinder A, Figs. 4190, 4191, 17 centimètres in diameter, and armed with iron pins or teeth 5 millimètres square, let 4 centimètres into the cylinder and projecting 2 centimètres above its surface, and the iron cylindrical casing, one portion B B of which is fixed and the other portion C is removable. The bundle of 14 kilogrammes is compressed and rolled out between the toothed roller, which makes from 60 to 100 revolutions a minute, and the outer casing B and C which is provided with several projecting diamond-points. The parts of the bundle become heated successively, and, joining together, they at length form a flat lump. This lump, dragged slowly by the powerful friction of the teeth, makes one revolution while the cylinder makes 30 or 40.

4190.



4191.



To give an idea of this trituration, we may state that it requires a force of 5 horse-power, and that the bundle of caoutchouc, condensed by the close adhesion of the fragments of which it is composed, possesses at the expiration of ten minutes, the time required for the operation, a diameter of 18 or 20 centimètres and a length of 40 centimètres. Such are its dimensions at the moment when it was taken out of the *devil*, in which its form was quite different, as it was compressed between surfaces only 6 centimètres apart, and limited by the two ends of the cylindrical chamber only 35 centimètres distant from each other.

In winter, during the first quarter of an hour, the agglomeration of the caoutchouc is assisted by heating the cylindrical chamber up to 112° by injecting steam into the double bottom E, Figs. 4190, 4191, by means of a cock G. A rectangular aperture *d*, or several long and narrow apertures, allows the bundle or lump of caoutchouc to be seen and touched. When the operation is completed, the cover is taken off by removing the pin N and raising the handle M. The roll is then taken out, and replaced by another of 14 kilogrammes prepared in the same manner.

As the rolls sometimes acquire a high temperature in consequence of the great friction to which they have been subjected, which temperature would be retained in the middle of the lump for a long time by reason of the low conductivity of the substance, it is necessary, to prevent injury to the material, to cut them asunder through their axis. This is done with a kind of hand-saw without teeth. The heating becomes of more importance in machines of larger dimensions, giving rolls weighing from 28 to 30 kilogrammes; it may be partially avoided and the introduction of the air into the caoutchouc prevented by substituting for the iron pins rounded flutings, projecting 4 centimètres and having a breadth of 4 centimètres at their base.

When it is required to make these rolls up into blocks, they are placed in the stove and heated up to 112° throughout their mass; they are then rolled out into thick sheets between hollow cylinders heated internally up to 105° by steam, and fixed 3 or 4 centimètres apart. Six or eight of these sheets or tablets are then placed one upon another and put under a hydraulic press, where they are left to remain subjected to a great pressure for about a week. The pieces become joined together, and on cooling retain the form they have assumed, of a rectangular prismatic block. This block is kept in a cellar as long as possible, or stored away for several months.

To cut up one of these blocks, it is fixed with india-rubber paste upon the travelling plate or carrier of a machine-knife fixed like a saw for cutting veneer. The carrier is moved forward by means of a long screw, and the piece of caoutchouc is thus kept up to the edge of a very sharp horizontal knife in rapid reciprocating motion (600 to 800 strokes a minute). To destroy the elasticity and prevent the heating and consequent adhesion of the caoutchouc, a jet of cold water is made to play continuously upon the edge of the knife. When the block has been cut through, it is drawn back, raised by means of screws beneath the support ⅓, ½, or several millimètres, according to the thickness required, and again pushed forward as before. The sheets thus obtained are used to make tubes, bracelets, garters, balls, and various surgical utensils; all these articles, after they are made, should be sulphuretted to render their elasticity stable.

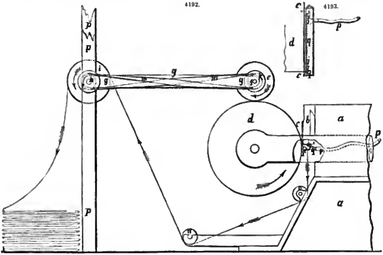
For cutting the blocks into sheets Charles Moseley invented a machine which, among other improvements, has a drawing or taking-up motion for keeping the sheet of India-rubber at one even tension, and so producing a greater uniformity of thickness and smoothness of surface.

The motion consists of two levers fixed upon the centres of two rollers. One of these rollers revolves in a fixed bearing, and the other roller rests upon the block of india-rubber to be cut into sheets: this roller rises or falls according to the diameter of the block. As the block revolves it comes in contact with the cutting knife, which by an oscillating motion cuts from it a sheet which passes over guide-rollers. As the block revolves it gives a motion to the roller bearing on it, which by means of straps and pulleys gives a rotatory motion to the roller, over which passes the sheet of india-rubber, and as the roller bearing on the block of india-rubber has a surface speed corresponding to that of the block, which decreases as the block decreases in diameter, the sheet of india-rubber is kept at one exact tension. The same effect may also be produced by self-acting cone-pulleys, to give a positive motion to the drawing roller corresponding to the decreasing surface speed of the block. It is necessary in cutting india-rubber to have a stream of water running upon the face of the knife to reduce friction; but to produce a smooth surface upon both sides of the sheet Moseley applies a stream of water to the back of the knife in addition to that at the front.

Fig. 4192 is an end view of Moseley's machine, and Fig. 4193 a plan of the arrangement for watering the back of the cutter.

4192.

4193.



a is the framing of the machine; *b*, the slide which carries the cutting knife *c*; *d* is the block of india-rubber held in movable bearings to be operated upon. Immediately over the india-rubber block *d*, and in contact with it, is the roller *e* fast on the shaft *f*, which moves in bearings in the two levers *g*, one of which is at each end of the roller *e*. The fulcrum of the levers *g*, and on which they are free to move, is the shaft *h*, which is the axis of the drawing or taking-up roller *i*; this roller *i* is covered with india-rubber, and revolves in fixed bearings in the upright standards *p*. On the shaft *h*, and also on the shaft *f*, which is the axis of the roller *e*, are keyed the two pulleys *k* and *l*, the crossed strap *m* being passed around them. Similar pulleys *k* and *l* and crossed strap *m* are made use of on the opposite ends of the shafts *h* and *f*, and three guide-rollers *n*, *o*, and *r*, are mounted in bearings fixed to the frame sides *a*. The apparatus for supplying water to the back of the cutting knife consists of a tin or light metal trough *q*, V-shaped or otherwise, which extends across the machine the length of the cutting knife. The trough *q* is closed all round, except on the inside edge or lip which is next the cutting knife, where suitable openings *j*, Fig. 4193, are left for the egress of the water, which is supplied to the trough *q* by means of a flexible pipe *p* of india-rubber connected by a branch to the pipe for supplying water to the front of the cutting knife, or from other suitable source at the back of the machine. The trough *q* is fixed under the slide *b* which carries the cutting knife *c* by a thin metal flange fast to and projecting from the trough *q*, and bolted in between the face of the slide *b* and the cutting knife *c*, and it is thus carried backwards and forwards with them, the flexible pipe *p* being made sufficiently long for that purpose; this motion assists in the distribution of the water along the block of india-rubber *d* from which the sheets are cut.

The mode of operation is as follows;—The attendant having put the machine in motion and turned on the supply of water, the sheet of india-rubber as it is produced by the action of the cutting knife is, as indicated by the arrows, passed over the guide-roller *r*, under the guide-rollers *o* and *n*, and over the drawing or taking-up roller *i*, which revolving and being covered with india-rubber has sufficient bite or hold on the sheet to draw it forward with the required tension. The speed of the roller *i* is required to decrease with the size of the block of india-rubber *d* under operation, for as the sheet is cut from it less length is produced during each revolution of the block *d*, and as it decreases in circumference, its rotatory speed being the same, the roller *e* in contact with it will be driven slower, and will communicate its decreasing velocity by means of the crossed straps *m* to the taking-up roller *i*, so that the sheet of india-rubber will be taken up as it is produced and deposited in folds in front of the machine.

Guibal easily obtains solid cylinders of caoutchouc by placing in a cast-iron mould one of the rolls as soon as it comes from the *devil*. The roll being placed vertically in the mould, an iron piston or ram is put upon it, and then placed under a hydraulic press. When the maximum pressure has caused the roll to assume the cylindrical form, the ram is fixed in this position for twenty-four hours, or even longer, to allow the caoutchouc time to cool and set.

These cylinders are afterwards cut up into sheets by means of the knife described above; but in this case, the section having to be made according to a spiral, the cylinder must be made to revolve, not by the uniform motion of its axis, but according to a uniform velocity of the sheet taken off by the knife. M. Guibal has solved this difficult problem by a very simple and remarkable contrivance. The rotary motion is communicated to the cylinder of caoutchouc by means of an endless strip of linen cloth, which, guided by rollers and always possessing the same velocity, since its length does not vary, allows each oscillation of the knife to advance by an equal quantity; it follows from this that the streaks or cuts slightly marked by each oscillation are equidistant, like those which are obtained by moving forward with a uniform motion the rectangular blocks placed horizontally upon the machine table.

Tubes and other hollow articles of all forms may be easily made of these flat pieces of caoutchouc by cutting the edges short off and bringing the sections in contact under pressure and welding them with a hammer upon an anvil. The operation must be performed in a warm place (about 75°), and the caoutchouc must be of the same temperature. If it has been previously cooled down to 32°, it must be reheated up to 105° to restore its elasticity and adhesive quality. The articles may be vulcanized cold after they are made, by a process which we shall presently describe.

Recently a new kind of rolling machine has been substituted for the *devil*, already shown in Figs. 4190, 4191. It consists of two hollow cast-iron cylinders. 33 centimètres in diameter and 75 in length, heated internally by steam; one of the cylinders is grooved longitudinally, and revolves with a greater velocity than the other in the ratio of 3 to 2, the motion being transmitted from one spindle to the other by means of toothed wheels of different diameters. The axes of both cylinders are in the same vertical plane, about 20 kilogrammes of caoutchouc in flat pieces is introduced between them, and as the machine is not covered in, the work can be easily watched. Moreover, as the roll of caoutchouc produced is not very thick, there is nothing to fear from an accumulation of heat in the middle of the mass.

Threads of caoutchouc are obtained by cutting up a piece of agglomerated caoutchouc 2 or 3 centimètres thick with a punch, or by means of the circular knife, into discs of 15 or 20 centimètres in diameter; these discs are then cut up spirally into strips, which are then subdivided into threads in the way described under the head of natural caoutchouc. The discs to be cut up into strips may be prepared in two other ways, by cutting them from the cylindrical blocks obtained by moulding the lumps taken from the deviling machine, or from cylinders prepared by rolling up a sheet of caoutchouc that has been worked and rolled between hot cylinders.

A great improvement has lately been made in the fabrication of *square* shreds in the form of a machine invented by M. Gérard. To produce threads by this machine, a thin piece of Para caoutchouc worked up with six hundredths of sulphur, and rolled out between hot rollers, is sprinkled, as it comes from the cylinders, with talc on both its surfaces. This sheet is then wound with a piece of linen cloth interposed upon a hollow mandrel, or kind of plate-iron bobbin. Its breadth is about 66 centimètres, its length 60 mètres, and its thickness varies from half a millimètre to 1, 2, or 3 millimètres, corresponding to threads whose section is a square having sides of one of these four dimensions. All the sheets thus rolled up are placed, by means of a rod passing through the hollow axis of the bobbins, into a stout vertical plate-iron cylinder, where they are exposed for two hours to a temperature of 285°, produced by steam injected under a pressure of four atmospheres into the closed cylinder. The long sheet of caoutchouc is then ready to be cut up in three cuttings throughout its whole length, a little margin being left at the edges to allow for any irregularities in the width.

The principal part of the ingenious machine producing this result, is composed of from 150 to 250 circular blades 7 centimètres in diameter and one-tenth of a millimètre thick, punched out of thin watch-spring steel. These blades or knives are kept at an equal distance from each other by brass washers from one-half a millimètre to 1, 2, or 3 millimètres thick, and 6 centimètres in diameter, all firmly held together by a nut on the end of a stout spindle. Beneath is a solid half-hardened india-rubber cylinder fixed upon a spindle parallel to the former, and in the same vertical plane. This cylinder, into which the knives slightly enter, supports the threads as they pass and are cut. The sheet of caoutchouc, moistened with water, is then placed between the knives, which are raised for a moment in order to mark a marginal border in front, and the rapid motion of 1500 revolutions a minute communicated to the spindle, whilst the solid india-rubber cylinder makes only 8 or 10. A continuous flow of small jets of water prevents adhesion and friction, and a kind of brass comb separates the threads. So fine are the sections, that the sheet of caoutchouc issues from between the knives without any apparent division having been made; but the lightest touch shows the 150 to 250 threads. These threads are tied up into skeins and cleansed, first in a solution of potash heated up to 212°, which softens the surface, and then in pure water. When they have been dried in the air, they are passed over a table between vertical round brass teeth, to destroy any slight adhesion; they are then ready for weaving. This machine makes in a given time as many threads as ten or fifteen common machines.

Solid balls of caoutchouc are made by placing the end of a roll against a revolving cylindrical rasp, formed of a sheet of iron punched full of small holes and having the burr on the outside, like a sugar-rasp. The great friction caused by the rapid motion of the rasp, 500 to 600 revolutions a minute, soon divides the mass of caoutchouc up into small fragments, which, having become heated by the friction, have acquired so adhesive a property that they form only a soft end pulpy mass. While in this state, it is made into an irregular ball by hand and placed in a cast-iron mould having two turned and polished hemispherical cavities; these two halves may be powerfully pressed together by means of a hoop and screw. A small quantity of the soft material is pressed out of the joint and forms a ridge; this is removed by changing the position of the ball in the mould. The pressure is then increased, and the ball left to cool; in twelve hours the ball will become very hard, and may be taken out of the mould. To restore its elasticity, it is kept for half an hour in a stove or in water heated to 122°, and then left to cool in an ordinary temperature.

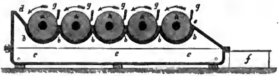
Thin filaments of caoutchouc are prepared by a kind of rolling when hot. A roll is taken as it comes from the deviling machine and flattened by pressure or cut in two longitudinally by a plane passing through its axis. The part thus obtained is heated in a stove up to 100° or 120°, and then passed several times between the cylinders of a rolling machine. These cylinders, which are hollow, are very gradually brought together during the process of rolling, and their temperature is raised to about 175° by putting red-hot bars of iron inside, or better, by an injection of steam. When the thickness of the caoutchouc is reduced to 2 or 3 centimètres, it may be folded double and passed through again several times in this way to render the substance homogeneous. The binding screws of each of the bearing blocks of the upper cylinder are then tightened end the sheet of soft caoutchouc again passed through; on leaving the rollers this time it is very thin. It may be obtained of any length as, to continue it, it is only necessary to supply the machine with material.

This thin filament is soft and very sticky; in this state it is put between two tissues and the three thicknesses passed between the rollers of a second machine. In this way stout waterproof fabrics are made, rather heavy, perhaps, but free from the strong smell of common *dissolvents*, as these are eltogether excluded from the preparation. When it is required to leave one face of the caoutchouc bare, one tissue only is used. The edges of this double tissue, folded in two and cut up into circular elliptical and rectangular forms, may be made to adhere at pleasure. The edges of the caoutchouc, put in contact and pressed hot, join and form a closed vase. A space is left in one of the corners for an ajutage, which is stuck in with caoutchouc paste. This ajutage, which is provided with a small screw stopper, is used to introduce into the vase or bag the solution for vulcanizing the caoutchouc and afterwards the air with which this kind of bag is distended to render it *elastic*.

When it is required to obtain the filament of caoutchouc alone, it is made to pass, as it comes from the hot rollers, into a bath of cold water very slightly alcalized, whence it is wound upon a reel; powdered talc is sprinkled on both its surfaces to prevent their sticking. If the rolling be effected rather slowly, between cylinders heated internally by steam, the sheets of caoutchouc retain the thinness so acquired. These sheets may be coloured by means of opaque powders. In this way zinc-white gives a whitish tint, and vermilion a beautiful red; a yellow or orange-red may be obtained with the ochres, blue with ultramarine, and black with bone, ivory, or lamp black. It is in accordance with these principles that M. Gérard produces from a single piece a kind of rug with designs in relief and a deep embossing. A stout strip of caoutchouc worked up with sulphur and coloured powders, and forcibly compressed between two hollow cast-iron plates heated by steam, first up to 240° for one hour, then for two hours up to 285° in order to effect the vulcanization. These remarkable carpets may be two yards long by one broad, and as each of the patterns of two yards may be multiplied indefinitely, whole pieces of a hundred yards length may be manufactured for use in long galleries.

Pastes and Solutions of Caoutchouc.—The thin sheets of caoutchouc and those obtained by crushing and drying, as described above, are very suitable for making pastes and solutions. They are first cut up into small pieces, and then placed in contact with each other in a closed vessel, with one-and-a-half times, twice, or three times their weight of essence of turpentine rectified, or better still, benzine. After twenty-four or forty-eight hours, the caoutchouc is distended and softened; in this state it is passed through a fine cylinder crushing machine, Fig. 4194. Each cylinder is 12 centimètres in diameter, and 40 in length, and it revolves in a semicircular trough *b*, forming the upper portion of a box *b c*, heated more or less by steam. The compound being put into the shoot *d*, runs down between the first cylinder and its trough. When the substance arrives on the other side of the cylinder, it meets the edge of a knife or scraper *g*, tangent to the surface of the cylinder; it then falls beneath the next, and so on throughout the whole number of cylinders. At *e*, it falls upon an inclined plane, and runs thence into a vessel *f*.

4194.



In this crushing machine, the five cylinders receive, from an equal number of endless screws fixed upon one spindle, the motion of an equal velocity communicated by these screws to each toothed wheel fixed upon the axis of each cylinder.

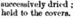
The solution so prepared is used for various purposes; to stick together the parts of india-rubber articles, to join rectangular pieces of agglomerated caoutchouc end to end, and to overlay certain fabrics to render them waterproof. It is sometimes laid on the back of wainscoting in contact with damp walls, and it is frequently employed to give a strong and supple joint to the dry surfaces of many parts of domestic furniture and musical instruments. This caoutchouc paste also forms, by a very simple process, a supple binding for certain kinds of books, such as ledgers, &c. The books to be bound are put into a press, cut, and all the leaves at the back, which have been cut straight, are laid over with three or four layers of solution successively dried; upon the last layer is placed a piece of fine linen cloth by which the leaves are held to the covers.

Oils for lubricating Machinery.—Colza oil, containing 1½ or 2 per cent. of caoutchouc, cut into very thin strips, and dissolved by a temperature of 250° to 265° kept up for five or six hours, becomes slightly brown and viscous; in this state it is very suitable for lubricating the rubbing parts of machinery.

Caoutchouc Cement.—This mastic is made by melting carefully, at a temperature of about 430°, caoutchouc cut very fine. As soon as it becomes fluid, slaked lime in the form of dust or powder is mixed with it; two parts of caoutchouc and one of lime give a soft cement; by doubling the proportion of lime, we obtain a firm but supple cement. These cements remain a long time ductile and tenacious; bottles may be hermetically closed by putting some of this material round the worn edges of a stopper. If we require the outside of the cement to dry, we must employ, for two parts of caoutchouc, one of lime, and one of red-lead.

Tubing.—The paste used in making tubes may be composed of 59 parts of caoutchouc, 35 of oxide of zinc, 5 of sulphur, and 1 of pulverulent lime. The strips of caoutchouc are first sprinkled with powdered talc to prevent their sticking; to render them more homogeneous, they are usually placed for an hour upon a hollow table heated by steam up to 250°. A strip is folded double, to a breadth proportionate to the diameter of the tube, and the edges cut with shears. The incision through the two thicknesses is made at an angle of 45° with the surface of one side, and consequently of 135° with the other, Fig. 4195. When the cylindrical form is given to the piece by means of an iron rod, the two surfaces of the section fit each other, as shown in Fig. 4196, and a pressure with a bar or a few blows with a flat rule is all that is required to make the edges adhere firmly.

4195.



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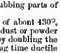


The tubes are in this way made upon smooth iron rods from 5 to 15 millimètres in diameter and from 10 to 13 mètres in length, and sprinkled with talc. When the joint is effected, the tubes are wrapped in a cloth and vulcanized by heating them for an hour and a half or two hours to a temperature of 270° to 285°, four hundredths of sulphur having been introduced into the paste at temperatures varying from 105° to 212°. For this purpose the tubes with their rods are placed in a vertical cylinder from 12 to 13½ mètres in height and hermetically closed. Steam is then introduced, and the temperature kept at 273° by means of a gauge indicating a pressure of three atmospheres. When the tubes have cooled, the rods are withdrawn. Should the tube stick to the rod, the adhesion is destroyed by injecting water between them with a small hand-pump.

Large Sheets of Caoutchouc, Waterproof Fabrics, &c.—Processes producing large sheets of caoutchouc are employed for obtaining pure or coloured layers of that material upon silk or linen fabrics, or smooth sheets of large size, either of pure caoutchouc or mixed with colouring oxides. The process is effected in the following manner;—The caoutchouc is first dipped into hot water, cut up into shreds, crushed between rollers, washed and purified in the way we have already described. The shrivelled strips so obtained are dried for twenty-four hours in a stove, and then immersed in three times their weight of rectified essence of turpentine; in this state they are left from twenty-four to forty-eight hours in covered wooden boxes lined with plate iron, and containing 500 litres. The shreds of caoutchouc, distended by the essence, are then distributed into eight cylindrical capsules, the bottoms of which are perforated like a skimmer; the thickness of the substance in each capsule is about 6 centimètres. The eight capsules are placed in a cylindrical column closed by a cover and made to fit tight over a wide-mouthed vessel containing essence of turpentine previously rectified. The essence is then made to boil, and the rising vapour passes through the capsules, heating to nearly 322° the caoutchouc contained in them, which becomes thus more regularly and intimately penetrated with essence. The vapour of the essence escapes at the top of the column through a side pipe which takes it into a common serpentine pipe where it is condensed, giving again distilled essence fit for subsequent operations. After two hours, the capsules are taken out of the column, and their half pasty contents poured into the barrel of a vermicelli press, provided with several graduated wire-gauze screens, supported on plates pierced with holes. The pressure exerted upon the piston by means of an iron screw, forces the caoutchouc pulp through the three or four screens. By this means it is better separated, as solid foreign matters, as well as the hard portions, are left in the pump-barrel.

The soft substance is next rolled and kneaded beneath cylinders similar to those already described, either alone or mixed with a few hundredth parts of ultramarine blue, orpiment, zinc-white, vermilion, or half a hundredth part of lamp-black (calcined), to make a blue, yellow, opaque white, brown, red, or black paste. Three or four hundredth parts of sulphur may be added if it be wished to vulcanize the material afterwards by merely heating it up to 275° to 285°. If the paste while being kneaded is not sufficiently soft, from half to one part of essence of turpentine may be added, which makes altogether three and a half or four parts for one part of caoutchouc; the paste is then ready to be laid on the fabrics. This is effected in the following manner.

In a part of the factory specially devoted to that purpose, well ventilated, and free from dust, a double frame supports, at a distance of 28 to 29 mètres apart, two cylinders 60 centimètres in diameter, and $1^{m}\cdot 50$ in length, revolving upon their axes, which are placed horizontal and parallel to each other. Over these two cylinders is passed a stout endless band, which may be tightened at will by means of binding screws upon the bearing blocks of the axis of one of the cylinders. The fabric $1^{m}\cdot 30$ to $1^{m}\cdot 33$ broad, which it is required to overlay with caoutchouc, is laid upon this band, and the two ends are sewn together, so that it too forms a continuous circuit and follows with the rotation of the cylinders all the motions communicated to the band. A transverse bar of wood, or better of iron, forming a kind of knife with a rounded edge, may be brought into contact with the fabric by two adjustment-screws; this serves to limit the thickness of the layer. A second transverse bar, parallel to the former, with rounded angles and covered with swan-skin, is placed under the endless band to keep the fabric perfectly horizontal and to regulate the pressure of the upper bar.

All being thus arranged, the paste is poured upon the fabric in front of the bar; and the two cylinders being set in motion, the band and the fabric upon it move along together, dragging the paste beneath the bar with a speed of 10 mètres a minute, so that in seven minutes the whole 69 mètres are covered. It was necessary formerly to wait at least two hours for the essence to evaporate before applying a second layer; in this way from twenty-eight to thirty hours were requisite to apply fourteen layers. But Guibal and Cuminge have reduced the whole duration of this operation to two hours by means of a new arrangement.

This arrangement consists in placing under the band at a distance of 1 mètre from the transverse bar A, Figs. 4197 to 4201, the two latter of which show the details of the bar or knife, a closed vessel, being a kind of box of plate iron B C D slightly bulging, as shown in Figs. 4197 to 4199, upon which the band rests throughout its whole breadth and for a length of 5 mètres. Into this vessel steam passes freely through a pipe E from a boiler in which the temperature is kept at 194°. The condensed steam flows out through the tubes $b'c'$ towards the water return. The heat thus transmitted to the thin layer of caoutchouc paste hastens the evaporation of the essence of turpentine employed. Besides this, a refrigerator F, formed of two slabs placed together like a roof, and having a slope of 45°, is erected over the fabric for a length corresponding to that of the vessel beneath. As the vapour exhaled from the paste meets the slabs, it is cooled by the water which falls upon them continuously from above from a pipe G parallel to their ridge, and pierced with holes on each side. The equal dissemination of the water over the whole surface is secured by fixing upon each slab a piece of coarse linen or canvas. The vapour of essence of turpentine or of *benzine* is condensed against the lower faces of the slabs, and, flowing down, collects in the channels I, which take it to a common receptacle J on each side.

In seven minutes each layer is spread and dried upon the fabric, which is wound alternately upon the two reels K L, so that the fourteen layers are laid on in two hours. As soon as the last layer is sufficiently dry, the fabric is wound off upon a portable reel. If the caoutchouc contain 3 or 4 per cent. of sulphur worked into it by kneading, it may be vulcanized by simply exposing the fabric to a temperature of 270° to 275° in a cylinder with a double envelope heated by steam up to 291° under a pressure of four atmospheres. The following composition is used by Guibal as a cheap and durable coating, free from all unpleasant smell;—

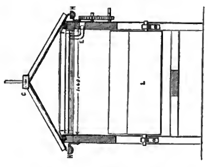
Purified caoutchouc	33
Ground litharge	50
Carbonate of lime	10
Lamp-black	2
Sulphur	5
	100
Benzine	100

The above method of vulcanizing is, however, employed only for linen fabrics; for silk and woollen goods would become crisp at so high a temperature. These are hung up in a cylindrical stove 3 mètres in diameter and 5 mètres high, which is heated for twelve hours by steam circulating under a pressure of four atmospheres through tubes at the bottom. During one and a half of the twelve hours the temperature is at 268° to 275°. These fabrics, which are intended for cloaks and hunting and shooting overcoats, are coated with a composition consisting of 30 parts of caoutchouc, 50 of porphyrized litharge, 10 of chalk, 2 of lamp-black, and from 4 to 5 of sulphur.

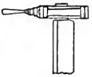
The same arrangements serve to coat a fabric upon both sides, by simply turning it over upon the endless band; in such a case more than five or six coatings are seldom laid upon each side. In the same way, four or five layers may be put between two pieces of cloth by laying two or three coatings upon each, and passing the two, placed face to face, between two rollers, which would make them adhere firmly.

The same machine is used to make large thin sheets of caoutchouc alone, either pure or mixed with pulverulent matters, such as sulphur and the colouring substances, zinc-white, ultramarine, ochre, lamp-black, and so on. In this case, a dressing of paste and two or three layers of a mixture of equal parts of molasses and gelatine must be first spread upon the endless band, which is stretched between rollers 14 mètres apart, occupying the place of the reels K L. This coating, which is sufficiently dry not to stick to the substances placed upon it, keeps supple for a long time by reason of the hygroscopic property of molasses. Upon this consistent coating as many as forty layers of the caoutchouc paste is laid to obtain a thickness of 1 millimètre; each layer, spread in ten minutes, requires one hour to dry, so that forty hours are required to spread and dry the forty layers. The sheet of caoutchouc is easily detached from the band, as the gelatinous coating prevents adhesion; it is afterwards sprinkled with very fine sifted talc and wound on a reel.

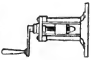
4199.



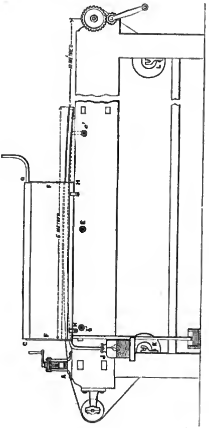
4201.



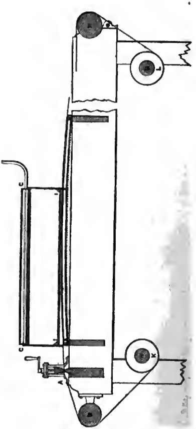
4200.



4197.



4198.



Articles of all shapes may be made out of this sheet, and afterwards vulcanized by simply heating them up to 275°, if sulphur has been previously mixed with the paste. The excess of sulphur may be removed from the articles after they are vulcanized, by immersing them for an hour in a boiling solution of soda or caustic potash; and the surface may be made softer by passing them through a bath of hydrochlorite of potash (Javelle liquor) heated up to 140°.

The method of dissolving and distending caoutchouc by a mixture of sulphuret of carbon and caoutchouc cold in a closed vessel, and then kneading in a press which forces the paste through fine wire gauze, is employed to prepare a coating to be put between two fabrics unwound from two cylinders, and uniting beneath the rollers of a rolling machine. The paste possessing sufficient fluidity holds the two together, and renders them waterproof. The sulphuret of carbon is more completely and more quickly volatilized than essence of turpentine, and leaves less smell. To moderate the evaporation and increase the adhesion, benzine may be substituted for a portion of the sulphuret of carbon.

The rolling machine and cylinders should be enclosed and well ventilated to protect the workmen from the noxious influence of the sulphuret of carbon.

Uses of the Sheets and Strips of Caoutchouc cut by the Machine-knife.—A great variety of articles may be made of these pieces before they are vulcanized, whether they contain 5 or 6 per cent. of sublimed sulphur, the action of which will show itself later by being raised to a temperature of 275°, or whether vulcanization is to be effected cold by chloride of sulphur dissolved in sulphuret of carbon. In any case, these pieces of caoutchouc, rendered supple by a temperature of 76° to 86°, are formed into all sorts of shapes before they are vulcanized; and if the articles produced are small figures or balls from 5 to 8 millimètres thick, their regularity is perfected by means of a mould into which they are placed hot, a temperature of 212° to 248° being sufficient to ensure correctness of form, and from 271° to 275° to fix the form acquired by vulcanizing the material. We shall give a sufficient idea of the processes employed in making a vast number of articles of this nature by describing the manufacture of hollow balls.

Small hollow balls of 8 to 12 centimètres in diameter are made of strips of caoutchouc mixed with sulphur, reduced to a thickness of 5 or 6 millimètres, by rolling, or by being cut with the oscillating knife. In all cases, four segments of a sphere are cut out of these strips according to models, and the edges joined by pressing them between the thumb and finger or with a caoutchouc paste, sulphur, sulphuret of carbon, and benzine, care being taken to enclose as much air as possible. They are then placed between the two hollow half-spheres or shells of a grooved mould a little smaller than the ball formed of the segments; the two shells are held together by thumb-screws. When all the moulds have been filled and screwed up, they are placed in the steam vulcanizing cylinder; here each ball swells by reason of the air inside dilating under the influence of the temperature, presses against the smooth or grooved face of the mould, and soon after the temperature has reached 266° becomes set by being vulcanized; the pressure of the confined air is sufficient to keep the ball distended. These balls are used as indoor toys, where harder ones would be dangerous.

Larger balls, such as those used for foot-ball and similar games, are made in the same way; but the necessity for greater consistency and elasticity requires the insufflation of compressed air. This was formerly effected by placing a small round piece of caoutchouc in the form of a washer on the inside to double the thickness at that part, and, after the ball was moulded and vulcanized, inserting, through a hole bored in this double thickness, the end of the blow-pipe of a compression-pump. When the ball was sufficiently distended, the pipe was withdrawn and a small conical iron plug inserted in its place. This manner of closing the hole was, however, defective, for a shock such as that caused by a blow or a bound soon blew out the plug, and the ball collapsed. This accident is now avoided by means of a very simple contrivance. Instead of putting a little disc of caoutchouc mixed with sulphur on the inside before the ball is closed up, as described above, a thicker disc, free from sulphur, is so applied. When these balls have been moulded and vulcanized in the steam-cylinder by a temperature of 275° in the manner already described, they are too feebly distended to enable the pressure inside to withstand the external pressure. They may, however, be easily distended to a greater degree, and kept in that state. This is done by simply inserting the point of a pipe communicating with a blowing machine. When the ball is sufficiently distended, the pipe must be withdrawn without allowing any of the compressed air to escape. This difficulty is surmounted by squeezing between the thumb and finger the thick disc of caoutchouc on the inside, which is still in its normal state, since it contains no sulphur. As it still retains its adhesive property, therefore, the pressure of the fingers is sufficient to make the sides of the aperture adhere, and so close it hermetically.

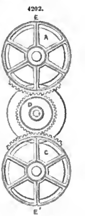
India-rubber Carpets.—We have already referred to the carpets, or mats, formed of a single piece of caoutchouc, manufactured by M. Gérard. In fabricating these articles he places a thick sheet of rolled caoutchouc between two cast-iron chests 50 centimètres in depth, strengthened by strong stays, and closed by a thick bolted lid of cast iron. The lower chest bears the rectangular moulds of cast iron, having hollows and projections sculptured and engraved upon them, in order to produce, by means of a heavy pressure transmitted by two iron screws, deep impressions; regular designs, bordered by a truly artistic framing of bas-reliefs, or medallions, are thus obtained between the faces of this kind of large embossing machine. At the moment when the pressure produces its effect, steam, under a pressure of four atmospheres, is injected into each of the two chests, so as to raise the temperature throughout the whole mass during one hour and a half to 284°. When sufficiently cooled, the screws are loosened and the caoutchouc removed.

It is possible in practice to obtain carpets two, three, or even twenty-five times this length, by continuing, one after the other, two, three, or twenty-five similar impressions upon the same sheet of caoutchouc. Care must be taken, in joining the moulds, to leave the contiguous portions exposed to the air, to avoid vulcanizing them a second time, which would render such parts of the carpet too hard.

The paste should be formed with 50 parts of caoutchouc, 15 of ravelled linen, 25 of oxide of zinc, 4 of sulphur, 5 of lime, and 6 of chalk. The 5 parts of lime serve to absorb the hydrosulphuric acid which is continually generated during the sulphuration, and to prevent this gas from causing flaws. The sticking of the moulds may be prevented by rubbing their surfaces before each pressure with a greasy cloth, or moistening them with soapy water.

The Manufacture of Machine Belts.—The following is the method employed by Aubert and Gérard in the manufacture of strong machine belts. The raw caoutchouc successively dipped in warm water, passed through the crushing machine, washed, dried, and agglomerated, then well kneaded with ·05 of its weight of finely-powdered sulphur between cylinders heated internally by steam to 120° or 140°, gives a very homogeneous paste, which is spread over a stout linen cloth and made to penetrate all its interstices by means of a machine called a *Spreader*, Fig. 4202. This machine is composed of three hollow cast-iron cylinders, A, B, C, of equal diameter, heated internally by steam introduced through the axis of a hollow spindle turning in a stuffing box; these cylinders are each furnished with a cog-wheel. Motion is imparted to the cylinder B, and transmitted by its toothed wheel D to each of the other wheels E, E′; the diameter of each of which is double that of the wheel D. It follows from this arrangement that the cylinder B turning twice as fast as each of the other two, the stout cloth, 1 mètre in breadth and 10 to 50 mètres in length, which passes between these cylinders receives the caoutchouc paste with so great a friction that it is penetrated by it, and the sheets thus prepared being placed one upon another, in number from three to ten, and passed between the heated cylinders of a rolling press, are formed into a solid mass. They are then cut up by a machine-knife according to the size of the wheels which they are intended to drive. To give them greater strength, and to render their edges smooth, they may be enveloped in a cloth prepared in the same manner and the joint covered with a narrow strip, which will render the whole envelope solid with the subjacent tissues.

4202.



Vulcanization is then effected by placing the belts in wrought-iron moulds forming a rectangular groove, which has been previously soaped, and which then receives an equally smooth plate of iron extending 10 or 12 millimètres beyond it. All the moulds thus filled are placed upon the lower chest of the vulcanizing press previously described. When the whole of the surface of this is covered with moulds the upper chest is lowered, by means of an endless screw working into the two cog-wheels which turn the screws of this press, and during the time that the pressure is exerted the temperature in the moulds is raised, by steam under a pressure of four to five atmospheres, to 284°. Under these conditions an hour suffices to vulcanize the belts. Then the upper chest is raised, the belts withdrawn from the moulds, and replaced by a second length in the same moulds. This second length is vulcanized in the same manner as the first, and the process is repeated until the whole length of belt has been vulcanized.

As contact with the iron distributes the heat rapidly, the time necessary for vulcanizing is, comparatively with vulcanizing by confined steam, diminished by one-half, from one hour to one hour and a half, instead of two hours to two hours and a half. The extremities of the moulds are slightly hollowed out, in order that in changing the place of the belt it may not be found twice vulcanized near the line of demarcation.

Hard India-rubber.—About the year 1848 a branch of industry was founded in America by Goodyear, in which advantage was taken of the properties of caoutchouc hardened by its combination with sulphur, in proportions much larger than those which constitute the compound known under the name of *Vulcanized India-rubber*.

The following is the method of preparing this substance;—

The raw materials are obtained from the products of a cheap and inferior quality, imported from Java and India in blocks containing foreign matters requiring a special purification. The lumps, more or less *voluminous*, of this raw caoutchouc, are put into tanks containing water which is kept at a temperature of from 110° to 120° during thirty-six to forty-eight hours. When these are sufficiently softened, they are cut up by means of a large and sharp thin-bladed knife into pieces of about 1 kilogramme in weight and between 6 and 12 centimètres thick. These pieces are crushed and kneaded between two cylinders slightly wetted, turning in contrary directions, the one making one revolution, the other two-thirds of a revolution a minute. The strips thus obtained, rough and full of holes, are next torn into small shreds by means of a machine similar to that employed for preparing the pulp in the manufacture of paper. When the continuous flow of water in this machine has entirely eliminated the earthy and other foreign matters, the caoutchouc is lifted out in a kind of floating pulp, and dried upon cloths fixed in frames; care must be taken not to raise the temperature of the current of air to a degree which would render the caoutchouc adhesive and cause it to retain a portion of the water.

The dried substance is then kneaded for about an hour by being made to pass several times between two cylinders, heated by an injection of steam to between 120° and 140°.

The pasty consistency of this mass admits of the easy incorporation with each 100 kilogrammes of caoutchouc of 50 of stone sulphur, reduced to powder and passed through a brass sieve No. 90 to 100 or 110 (that is to say, showing, when viewed under a lens, 90 to 110 threads upon each side of a square of 27 millimètres).

The sulphur being intimately blended and uniformly spread throughout the mass, the cylinders are brought closer together by means of regulating screws acting upon the bearing blocks, so as to reduce the paste to a sheet of the required thickness (of 2 to 7 millimètres, but more usually of 3 to

4 millimètres) for the manufacture of combs and common articles; the sheet is cut up according as it is rolled, into tablets of 40 centimètres in breadth and 60 centimètres in length.

These soft tablets are received upon frames, upon which is stretched moistened canvas, and plunged into warm water at about 80°, in order to take off the excess of heat and render them more firm, and to effect the contraction which otherwise would be produced at the moment of vulcanizing, and which would detach them from the sheets of tin or of glass. They are then dried and placed upon sheets of tin or glass, previously covered with a thin layer of lard: then, to ensure their contact, a very smooth iron roller is passed over it, and, to prevent the caoutchouc from sticking to the roller, the latter is powdered with silicate of magnesia (talc).

After remaining twenty-four hours in a horizontal position, which increases the consistency of the tablets, the plates thus charged are placed upon iron frames mounted on a bed-plate which keeps them in a position inclined at about 45°, in order, on the one hand, that the tablets may not run as they become soft during the sulphuration, and, on the other hand, that the drops of condensed water may run off without staying on the paste.

The bed-plates, mounted upon wheels, are run upon rails into a stout plate-iron cylinder, 1 mètre in diameter and 6 mètres in length.

This is closed by a kind of door of cast iron having a circular flange, which fits into a groove round the edge of the cylinder half filled by a roll of supple alkaline caoutchouc mixed with ·25 of tow. The door being firmly closed, steam is injected through a pipe full of holes fitted to the bottom throughout the whole cylinder.

The steam, furnished by a boiler under a pressure of five atmospheres, is gradually distributed so as to raise very slowly, in two or three hours, the temperature in the interior of the cylinder to 275°.

This temperature is maintained for seven hours.

If tablets of caoutchouc of 10 to 12 millimètres thick had been employed, it would have been necessary to raise the temperature more slowly, say in four hours, to 275°, and to keep it there during eight hours.

The injection of steam is then stopped, and they are allowed to cool slightly, after which the air is readmitted into the cylinder. The door may then be removed, the frames withdrawn, and when completely cold the caoutchouc lifted off, the tablets having become very firm by the combination of the sulphur with the caoutchouc. If the proportion of sulphur were augmented, or if the temperature were raised too high, the product would become harder, but it would be too fragile. It has been proved that by mixing an excess of sulphur a hard and brittle compound can be obtained, containing ·48 of sulphur combined; whilst hard india-rubber of good quality should contain only ·33 of sulphur.

During the sulphuration in the cylinder, the steam in condensing falls in drops of water upon the yet soft tablets. The water bringing with it the rust (oxide of iron) formed upon the inner surface of the cylinder, these substances often penetrate deep enough to form bubbles and faults in the thickness of the tablets, and so lessen much the value of the articles made from them.

A method could probably be devised to prevent these defects, either by maintaining the pieces of caoutchouc in a vertical position between two sheets of tin, or by placing, above the bed-plate which carries the inclined frames, two sheets of tin in the form of a ridge-roof; a roof of this kind would receive the drops of water from above and would cause them to drain off beyond the tablets.

After the tablets are manufactured, they are employed principally as raw materials for combs. For this purpose the tablets are cut into the usual forms by means of a narrow saw, called a fret-saw, which follows the outlines already traced by a steel point. The pieces thus cut up are thinned towards one of their edges, like a sword blade, by means of planes, and further smoothed by rubbing them on a slate. The teeth are then cut by a circular saw. Nothing then remains but to polish them, which is easily accomplished by rubbing them with a mixture of powdered pumice-stone and tallow.

Pieces of various shapes may be sawn out, turned, or planed, and then easily bent, by dipping them for some minutes into boiling water, or by heating them in a stove. If they are plunged into cold water after they are bent, they will immediately set in the acquired form.

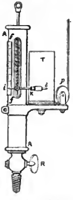
The thick sulphured paste of caoutchouc may easily be spread upon bronze moulds, bas-reliefs, and these medallions afterwards exposed in the steam-cylinder to the temperature of 275°; when cold they retain the acquired forms, with the polish of the moulds.

INDICATOR. Fr., *Indicateur*; Ger., *Indicator*.

The steam-engine *indicator* is an instrument for ascertaining the pressure of the steam in the cylinder of steam-engines, and the law of its variation during expansion, and during a double stroke of the piston. The instrument was invented by Watt and improved by MacNaught. In its simplest form, it consists of a small hollow cylinder A A, Fig. 4203, which may be screwed upon the head of the cylinder of the steam-engine; steam is let into it by means of the cock R. A piston, the rod of which is visible through the longitudinal aperture *f f*, works in this cylinder A A, and through the upper end. The rod is surrounded with a spiral spring fixed to the small piston and to the upper end of the cylinder A A. The steam, in virtue of the pressure which it exerts upon the small piston, compresses this spring; and, if the spring is carefully made, the quantity by which it is compressed in the vertical direction is proportional to the pressure exerted upon the small piston; so that the pressure in the cylinder of the engine is measured by the quantity by which the small piston rises above its initial position, which position answers to a pressure of *o*, or to an absence of pressure. This displacement of the small piston is measured on the outside by means of a style *i* K, fixed to the rod by a stud projecting through the longitudinal opening. The end *i*, of this style moves over a divided scale fixed to the cylinder, and this gives the measure of the pressure.

The instrument is very valuable, even when reduced to the parts which we have just described, as it enables us to ascertain the pressure in the steam-cylinder, a pressure that is always considerably less than that exerted in the boiler, and which is measured by the gauge. But the improvements which have been made in it enable it to register the variations of pressure, and to express the law of the variations by a curve. The following description will show how this is done;—Upon a support fixed to the cylinder A A. is a drum T, revolving about its axis and having a strip of paper rolled round it. A groove on the lower end of this drum holds a cord which passes over a pulley *p*, with a horizontal axis and fixed upon the same support, and is carried up vertically to a horizontal arm or stud on the engine piston-rod. It follows from this that the drum turns upon its axis by a quantity proportional to the displacement of the piston of the engine. A spring, similar to the main-spring of a watch, fixed inside to the side of the drum and to a fixed point, being compressed during the rotation of the drum, corresponding to the upward stroke of the engine-piston, brings back the drum to its original position during the downward stroke. To the end K of the style *i* K, is fitted a pencil, which makes an obtuse angle with the style, and the point of which rests upon the drum. During the simultaneous motion of the small piston and the drum, this pencil traces upon the surface of the latter a curve which expresses the law of the variation of the pressure in the engine-cylinder; for the displacements of the pencil in the vertical direction, reckoning from the position corresponding to a pressure of *o*, are proportional to the pressure, and the rotation of the drum is proportional to the distance traversed by the engine-piston.

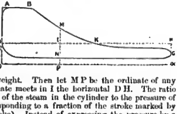
4203.



The arrangement we have described supposes that the circumference of the groove of the drum is at least equal to the stroke of the piston; but as this condition cannot always be conveniently fulfilled, the cord on coming from the groove is made to pass first over a little windlass moving with the pulley *p*, and having the same axis; a second cord, attached to the groove of the pulley, to which a sufficiently large radius may be given to make its circumference exceed the stroke of the piston, is carried up vertically and fixed to the engine-piston in the way described above. By this means the indicator may be applied to widely-different strokes.

If the sheet of paper which was rolled round the drum be unrolled after the experiment, we obtain a curve or diagram similar to Fig. 4204, and representing the law of the variation of the pressure during a double stroke of the piston. In a previous experiment, and before the indicator was screwed upon the cylinder of the engine, the drum was turned, and the pencil traced the horizontal straight line O X, which corresponds to a pressure of *o*, since the pressure of the atmosphere was then acting upon both ends of the little piston. The straight line D H was also drawn corresponding to one atmosphere, which is very easy, knowing the compression to which the spiral spring is subjected under the pressure of a given weight. Then let M P be the ordinate of any part of the curve with respect to O X, which ordinate meets in I the horizontal D H. The ratio of M P to I P will express the ratio of the pressure of the steam in the cylinder to the pressure of the atmosphere, for the position of the piston corresponding to a fraction of the stroke marked by the ratio of O P to O X (O X being the whole stroke). Instead of expressing the pressure by a ratio, it may be expressed by a number of kilogrammes to the square centimètre, by merely choosing a scale in which I P shall represent $1^{k}\cdot033$, or by a number of pounds to the square inch by making the corresponding suppositions.

4204.



It will be seen by a reference to the diagram that the portion A B corresponds to the period of admission of the steam into the cylinder. The portion B M C corresponds to the period of expansion; the pressure, which was greater than that of the atmosphere, becomes equal to it for the position of the piston corresponding to the point K, after which it becomes less. The portion C N D corresponds to the period of emission during which the pressure is that of the condenser. This latter portion of the curve joins itself to the first at the end of this second stroke, and the diagram is the closed curve. When a certain advance is given to the admission or the emission, every circumstance of the motion is represented by the diagram.

This diagram enables us also to calculate the work corresponding to a stroke of the piston. Since the ordinate M P expresses the pressure, and the abscissa O P the distance passed over, the work of the steam upon the piston during a stroke is represented by the area O A B C X O. But for a similar reason, the work exerted upon the same face of the piston during the following stroke is expressed by the area O E N C X O. Consequently, the work developed upon the piston during one stroke is the difference of the two preceding, that is, it is expressed by the area comprised in the closed curve forming the diagram. This area may be computed by means of the *planimeter*, or by an approximative formula.

The form of steam-engine indicator formerly in general use was the MacNaught Indicator, just described, in which the piston and its guiding rod have the same range of motion as the pencil; but as the piston and rod were necessarily made quite heavy, and their range of motion extensive, in order to produce delineations on a sufficiently large scale, the momentum of these parts was so great, and the tremulousness of the spring so considerable, as to render the instrument unserviceable for application to engines having rapid movements. These defects have been remedied in the Richard's Indicator, the invention of Chas. Richards, of Connecticut, U.S.

Fig. 4205 is a plan of this instrument; Fig. 4206 is a side elevation; Fig. 4207 is a vertical section through the centre of the spring-case A; and Figs. 4208 to 4211 show parts of the instrument in detail.

NAZIONALE FIRENZE

CORRECTION.

In some few copies of No. 61 of this Dictionary, at page 1949, the following line occurs—"*Centrifugal Pumps of John and Henry Gwynne, of Hammersmith;*" this should read—"*Centrifugal Pumps of Messrs. Gwynne and Co., Essex Street Works, London.*"

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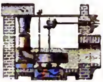

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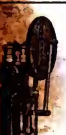

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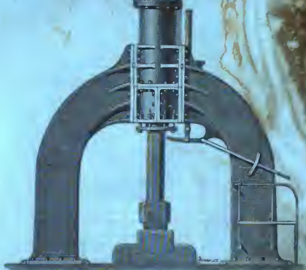

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